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RECYCLING AND REUSE OPTIONS FOR SPENT ABRASIVE BLASTING MEDIA AND SIMILAR WASTES

by

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABM	abrasive blasting media
ARRA	Asphalt Recycling and Reclaiming Association
ASTM	American Society for Testing and Materials
BDAT	Best Demonstrated Available Technology
BDL	below detection limit
Caltrans	California Department of Transportation
C&D	construction and demolition
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	<i>Code of Federal Regulations</i>
DNR	Department of Natural Resources
DTSC	(California) Department of Toxic Substances Control
EAF	electric arc furnace
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FOB	free on board
FR	<i>Federal Register</i>
IGT	Institute of Gas Technology
MTPY	metric tons per year
NFESC	Naval Facilities Engineering Service Center
OAR	Oregon Administrative Rules
OMB	Office of Management and Budget
PCB	polychlorinated biphenyl
ppm	parts per million
R&D	research and development
RCRA	Resource Conservation and Recovery Act
SIC	Standard Industrial Classification
SITE	Superfund Innovative Technology Evaluation
SSPC	Steel Structures Painting Council
STLC	(California) Soluble Threshold Limit Concentration
TCLP	Toxicity Characteristic Leaching Procedure
TIM	(Washington Department of Ecology) Technical Information Memorandum
UCD	use constituting disposal

VISITT	Vendor Information System for Innovative Treatment Technologies
WAC	Washington Administrative Code
WET	(California) Waste Extraction Test

RECYCLING AND REUSE OPTIONS FOR SPENT ABRASIVE BLASTING MEDIA AND SIMILAR WASTES

1.0 INTRODUCTION

This handbook is designed to help Navy personnel with waste minimization and pollution prevention efforts by assisting them to identify and apply recycling and reuse options for mineral-based spent abrasive blasting media (ABM) and similar waste materials. The handbook is intended as a technology transfer document to increase the awareness of recycling and reuse options for spent ABM and similar wastes. The following types of information will be included in the handbook:

- defining the contaminant and matrix characteristics for ABM and similar wastes
- outlining specific technologies for recycling and reusing these wastes
- describing how to identify and evaluate options for recycling and reusing these wastes.

The handbook does not address steel shot, glass beads, plastic beads, sodium bicarbonate, or wheat starch ABM.

Recycling spent ABM has the potential to significantly reduce waste generation while saving money. The reported production rate of spent ABM from eight U.S. Navy shipyards is in the range of 75,000 to 100,000 tons (68,000 to 90,800 metric tons) per year (Bryan et al., 1990). Promising waste minimization alternatives are available for managing ABM.

Specific processes and vendors are mentioned in many sections of this technology transfer report. Mention of a process or a vendor does not constitute a recommendation or endorsement. All descriptions and data are taken from literature data. None of the reported results are based on data collected by or first-hand knowledge of the authors.

2.0 WASTE CHARACTERISTICS

This section describes the physical properties and chemical composition of slag and mineral ABM and the contaminant content of spent ABM and similar wastes.

2.1 Characteristics of Abrasive Blasting Media

This section describes the types of ABM used to remove paint from ships, bridges, and similar large structures documents the physical and chemical characteristics of the ABM.

2.1.1 Types of Abrasive Blasting Media used at Shipyards

Many types of ABM are used to remove paint, coatings, and/or corrosion from industrial structures. Any ABM used at a U.S. Navy shipyard or at a private shipyard working on U.S. Navy vessels must meet Mil-A-22262b(SH) specifications. The qualified ABM are listed in Appendix A. Processed coal and metallurgical slags are popular sources for ABM, but natural mineral materials may also be used. Slag blasting media are typically used once in a blasting operation and then discarded, although tougher materials such as garnet can be cleaned and reused.

One widely used type of ABM is made as a byproduct of coal combustion. The ABM is a fused ferro-alumino-silicate formed when molten slag from a coal combustion boiler is quenched in water. The water quench cools the slag quickly, resulting in an amorphous, noncrystalline particulate. Thermal shock from the rapid cooling fractures the slag into rough, angular particles. ABM can be produced from the slag particles simply by segregating different particle-size grades using screens (Austin, 1995). Higher quality ABM can be made by performing an initial crushing and screening followed by magnetic separation to remove metal particles. The upgraded slag particulate is then screened to separate size grades. The 11 companies that supply ABM made from coal slag had total volume and sales in 1992 of 442,000 tons (401,000 metric tons) and \$19,500,000, respectively. Reed Minerals, the largest volume producer supplying about 62% of the sales, makes a product called Black Beauty™ (the use of trade names in this report does not necessarily constitute endorsement for use). Due to the dominance of the Black Beauty™ in the coal slag ABM market, many users incorrectly use the trade name as a generic term for coal slag ABM. Similar materials made by the other companies are marketed under other trade names such as Stan-Blast™ made by Stan-Blast Abrasives (17% of sales) and Black Diamond™ made by Foster Dixianan (10% of sales) (Paumanok, 1992).

ABM is also made from slag produced by pyrometallurgical processing to recover copper or nickel. The metallurgical slags are quenched to produce glassy fragments and then screened in the same manner as the coal slag. As with the coal slag, magnetic separation may be used to remove metal particles.

Copper slag is a mixture of ferrosilicate, ferro-alumino silicate, calcium silicate, magnesium silicate, and silica with trace amounts of antimony, arsenic, copper, and lead. Seven companies supply ABM made from copper slag with total volume and sales in 1992 of 187,000 tons (170,000 metric tons) and \$10,300,000, respectively. The largest suppliers are Kleen-Blast Abrasives (37% of sales volume), Minerals Research and Recovery (29% of sales volume), RDM Multi-Enterprises (21% of sales volume), and MDC Industries (7.5% of sales volume) (Paumanok, 1992). The copper slag materials are marketed under trade names such as Sharp Shot™, Apache Black Hawk™, and Copper Blast™. The copper slag ABM product trade-named Kleen Blast™ is imported from Canada.

Nickel slag is a mixture of magnesium ferro-silicate and silica with trace amounts of other metals (Austin, 1995). There are two suppliers of nickel slag ABM in the United States market. Green Diamond Abrasives produces Green Diamond™ nickel slag using slag from a smelter near Riddle, Oregon, with total volume and sales in 1992 of 45,000 tons (40,800 metric tons) and \$3,200,000, respectively. Kayway Industries imports about 5,000 tons/yr (4,540 metric tons/yr) of nickel slag ABM from Canada for sale in the United States (Paumanok, 1992).

Physical and chemical characteristics influence the recyclability of slag ABM. The regulatory status is the single most important factor because waste management practices controlled by the Resource Conservation and Recovery Act (RCRA) or state hazardous waste regulations reduce the flexibility in selecting and implementing recycling options. Physical properties such as particle size and shape and chemical properties such as total composition also affect the acceptance of spent ABM in commercial applications.

ABM produced from slag may contain elevated background levels of regulated metals. ABM from coal slag will typically contain nickel and vanadium and a variety of other metals depending on the coal that was used as the source of the slag. Copper slag from primary smelters contains elevated copper and barium levels and lower but significant levels of cobalt, trivalent chromium, and nickel. Copper slag from secondary smelters may contain significant levels of lead and arsenic. Nickel slag typically contains elevated concentrations of nickel, copper, and trivalent chromium and lower levels of cobalt and vanadium. Arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver are used to determine leachable metal toxicity by the U.S. Environmental Protection Agency (U.S. EPA) under RCRA. Some states, for example California, consider additional metals and total content as well as leachability in their definition of hazardous waste. It is unlikely but possible that unused ABM will be classified as a hazardous material by virtue of its background soluble or total metal content. A high background metals content in the virgin ABM means that the addition of a relatively small amount of metals-containing dust during blasting may cause the spent ABM to be classified as hazardous.

Most ABM are produced in at least three different particle size grades. In general, the coarser grades are more compatible with recycling as aggregate for portland cement concrete or asphaltic concrete because they mix better. Rounded particles are more suitable for use in portland cement, whereas sharp, angular particles are better for use in asphaltic concrete.

The chemical composition can affect the performance of spent ABM. The dark colors of slag ABM may limit acceptance in products with an appearance function where the slag materials replace lighter colored natural minerals. High chloride concentrations are undesirable in many applications. Sulfate concentrations or high alkali reactivity would make the ABM unsuitable for use as aggregate in portland cement.

Natural minerals such as silica sand, garnet, or staurolite are also used for ABM. Silica sand ABM is typically composed of mostly quartz with some garnet and feldspar and traces of lithic fragments such as hornblende. The fine silica particles produced by blasting with sand create a significant health concern, so use of sand as ABM is declining. Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form. The general formula for garnet is $A_3B_2(SiO_4)_3$, where A can be calcium, magnesium, ferrous iron, or manganese and B can be aluminum, ferric iron, chromium, or (in rare cases) titanium. The most common garnet minerals for use as ABM are $Mg_3Al_2(SiO_4)_3$ (pyrope), $Fe_3Al_2(SiO_4)_3$ (almandite), and $Ca_3Fe_2(SiO_4)_3$ (andradite). Almandite and almandite-pyrope solid solutions make the best abrasive grains. Andradite is softer and breaks down more easily. Staurolite is $(Fe^{2+}, Mg, Zn)_2Al_9(Si, Al)_4O_{23}(OH)_2$.

Mineral ABM may be naturally occurring sand or may be manufactured by crushing and size-grading using screens. Sand for abrasive blasting is produced by 48 companies operating 84 mines (Austin, 1995). Silica sand does not meet the requirements of the MIL-A-22262b(SH) specification due to the high free silica content. Ten firms produce garnet ABM with a total volume and sales in 1992 of 25,000 tons (22,700 metric tons) and \$7,800,000, respectively (Paumanok, 1992). DuPont, marketing Starblast™, is the only supplier of staurolite ABM. Unofficial sources estimate the 1992 volume and sales for Starblast™ at 55,000 tons (50,000 metric tons) and \$7,700,000, respectively (Paumanok, 1992). Similar to slag ABM, mineral ABM is available in different particle sizes, with the coarse grades more amenable to recycling into asphalt. However, unlike slag ABM, abrasives made from natural minerals contain low background metals concentrations. The matrix of mineral ABM is unlikely to contribute to total or leachable hazardous metals which can make recycling easier.

2.1.2 Physical Characteristics of Abrasive Blasting Media

As discussed above, the physical properties of ABM influence the selection of recycling options. Some key properties of unused slag and mineral ABM are shown in Table 2-1.

Table 2-1. Physical Properties of Unused Abrasive Blasting Media

Parameter	Coal Slag ABM Properties	Copper or Nickel Slag ABM Properties	Silica Sand ABM Properties	Garnet ABM Properties
Physical form	Angular, amorphous grains	Angular, amorphous grains	Rounded irregular, crystalline grains	Subangular, crystalline grains
Mesh sizes available (U.S. screen size)	10 to 100	8 to 80	6 to 270	8 to 300
CAS ^(a) number	68476-96-0	No data	No data	1302-62-1
Melting point (°F)	>2,000	2,400	No data	>2,280
Hardness (Mohs scale)	6 to 7.5	7 to 7.5	5 to 6	6.5 to 9
Bulk density lb/ft ³	75 to 100	84 to 95	100	130 to 147
Specific gravity	2.8	2.8 to 3.6	2.6	3.2 to 4.3
Water solubility	Negligible	Negligible	Negligible	Negligible
Color	Black	Black	White to tan	Wide variation, generally red to brown

(a) CAS is Chemical Abstracts Service.

Source: Compiled from Austin, 1995; Williams, 1991; and manufacturers' literature.

ABM is available in grades, based on particle size, ranging from extra coarse to very fine. The size grading available varies with the grit maker but some example particle size ranges for grades of expendable ABM are indicated in Table 2-2. The correspondence of screen size to screen opening is shown in Table 2-3 along with the Unified Soil Classification size ranges for sand, silt, and clay to provide a basis for comparing the size of ABM with typical soil materials.

**Table 2-2. Example Screen Size Ranges
for Abrasive Blasting Media^(a)**

U.S. Screen Size	Coarse (4.0 to 5.5 mil)^(b)	Medium (3.0 to 4.0 mil)^(b)	Fine (2.0 to 3.5 mil)^(b)
6	0	0	0
8	5	0	0
12	25	3	0
16	33	37	0.4
20	17	28	11
30	12	19	43
40	6	9.2	34
50	1.5	3.1	8.5
pan	0.5	0.7	2.9

(a) Percent of sample retained on screen.

(b) Anchor pattern given by grade of grit.

2.1.3 Chemical Characteristics of Abrasive Blasting Media

This section summarizes some recent data about the total composition and leachable metals content of unused and spent ABM. As discussed in Section 2.1.1, slag media may contain elevated levels of regulated metals. Pigments in paint chips removed by ABM increase the leachable metal content of spent ABM. Some common pigments containing RCRA hazardous metals include red lead, white lead, chromium yellow, chromium orange, molybdate orange, zinc yellow, chromium green, and chromium oxide green (U.S. EPA, 1990b, EPA/530-SW-90-059Y). Spent ABM in shipyards can contain paint chips with copper- or tributyltin-based antifouling paints or lead-based primers.

2.1.3.1 Chemical Characteristics of Unused Media. The approximate chemical composition of some example slag and mineral ABM materials in unused condition is shown in Table 2-4. Most coal slag ABM contains only small quantities of RCRA-regulated metals, and the vitrified form provides a leach-resistant matrix, so hazardous metal leachability should be low. For example, all Toxicity Characteristic Leaching Procedure (TCLP) leachable metal concentrations from Black Beauty™ ABM, as shown in Table 2-5, are far below the regulatory level for a toxic leachable characteristic. Metallurgical slag typically will have higher residual metal content but is still unlikely to have a RCRA leachable toxicity characteristic in the unused condition. The natural mineral ABM materials should have low trace metal content (see Table 2-5). The Mil Spec for ABM requires that unused material pass both the RCRA and the California leaching tests.

2.1.3.2 Chemical Characteristics of Media Used on Ships. Mare Island Naval Shipyard in Vallejo, California generated about 2,000 tons (1,800 metric tons) per year of spent ABM from sand-blasting submarines. Mare Island used ABM derived from a slag copper smelting that is sold under the trade name of Kleen Blast™. The average bulk elemental composition of Kleen Blast™ is as follows:

Iron oxide as Fe ₂ O ₃	23%
Silica as SiO ₂	45%
Alumina as Al ₂ O ₃	7%
Calcium as CaO	19%
Sodium as Na ₂ O	<0.2%
Potassium as K ₂ O	<0.1%
Magnesium as MgO	6%

Table 2-3. Correspondence of Screen Size Number to Opening Size

U.S. Screen Size	Opening Size (mm)	Opening Size (inches)	Unified Soil Classification
4	4.75	0.187	Coarse sand
6	3.35	0.132	
8	2.36	0.0937	
10	2.00	0.0787	
12	1.7	0.0661	Medium sand
14	1.4	0.0555	
16	1.18	0.0469	
18	1.00	0.0394	
20	0.850	0.0331	
30	0.600	0.0234	
40	0.425	0.0165	
50	0.300	0.0117	
60	0.250	0.0098	
70	0.212	0.0083	Fine sand
80	0.180	0.0070	
100	0.150	0.0059	
120	0.125	0.0049	
140	0.106	0.0041	
200	0.075	0.0029	
230	0.063	0.0025	Clay or silt ^(a)
270	0.053	0.0021	
325	0.045	0.0017	

- (a) Clay is soil passing a 0.003-in (0.075-mm) screen that is plastic (putty-like) and has strength after drying in the air, and silt is soil passing a 0.003-in (0.075-mm) screen that shows little or no plasticity and has no strength when dried in the air.

Source: ASTM, 1995, Specification E 11 and Standard D 2487.

The total copper content of Kleen Blast™ is about 0.2%. Copper or tributyltin from antifouling paints and lead and other metals from paint pigments may increase the metal loading in the ABM during sandblasting. The types and concentrations of metals depend on the types of paints and coatings being removed. Typical metals concentrations in the spent ABM at Mare Island are shown below:

	<u>mg/kg</u>		<u>mg/kg</u>
Copper (Cu)	3,120	Cobalt (Co)	70
Barium (Ba)	1,080	Nickel (Ni)	62
Zinc (Zn)	197	Lead (Pb)	33
Vanadium (V)	118	Arsenic (As)	25
Chromium (Cr)	90		

Table 2-4. Chemical Composition of Unused Abrasive Blasting Media

Component	Coal Slag ABM Comp. (weight %)	Copper Slag ABM Comp. (weight %)	Silica Sand ABM Comp. (weight %)	Garnet ABM Comp. (weight %)
SiO ₂	47.2	32 to 45	>99	36 to 37
Free SiO ₂	<1	<1	>99	<1
Al ₂ O ₃	21.4	3.0 to 7.0	0.15	20
FeO				30
Fe ₂ O ₃	19.2	23 to 48	0.045	2 to 33
CaO	6.8	0 to 19	0.011	1 to 2
MgO	1.5	1.5 to 6.0	0.005	3 to 6
K ₂ O	1.6	<0.1 to 1.2		
TiO ₂	1.0		0.013	2
Na ₂ O	0.6	<0.2		
MnO				1
As	<0.0001	0.01 to 0.04		<0.01
Co	0.00023	0.02 to 0.03		<0.01
Cr	0.00013	0.04 to 0.05		<0.01
Cu	0.00046	0.2 to 0.4		<0.01
Pb	0.00014	0.1 to 0.2		<0.01

Source: Compiled from Austin, 1995; Williams, 1991; and manufacturers' literature.

Table 2-5. Toxicity Characteristic Leaching Procedure Analysis Results for Unused Abrasives

Contaminant	Coal Slag Leachability ^(a) (mg/L)	Garnet Leachability (mg/L)	Regulatory Limit (mg/L)
Ag	BDL to 0.151	<0.05	5.0
As	BDL to 0.048	<0.1	5.0
Ba	BDL to 0.482	<0.1	100.0
Cd	BDL to 0.007	<0.02	1.0
Cr	BDL	<0.05	5.0
Hg	BDL to 0.041	<0.001	0.2
Pb	BDL to 0.605	<0.5	5.0
Se	BDL to 0.048	<0.1	1.0

(a) BDL = below detection limit.

Source: Reed Minerals, 1995.

2.1.3.3 Chemical Characteristics of Media Used on Bridges. The Commonwealth of Pennsylvania funded a study of beneficial reuse options for spent ABM used to remove lead-based paint from bridges (Weyand and Sutton, 1990). As part of the project, samples of spent coal slag and spent copper slag ABM were analyzed to determine the total composition and TCLP leachability. The total composition is shown in Tables 2-6 and 2-7 for coal and copper slag, respectively. The TCLP results are shown in Tables 2-8 and 2-9 for coal and copper slag, respectively.

Two of the copper slag samples had low TCLP leachable lead (see samples 7 and 9 in Table 2-9). The authors note that all three copper slag samples contain a higher concentration of elemental iron and ferrous iron than the coal slag samples. Elemental iron reduces lead leachability, leading the authors to propose iron stabilization as a possible mechanism. They also note that samples 7 and 9 required significantly more acid addition to maintain a final pH of 4.8. The greater acid requirement indicates more reserve alkalinity which may have reduced lead leachability in the TCLP test.

Table 2-6. Total Chemical Composition for Spent Coal Slag Media

Element	Total Composition of Slag Sample (wt %)					
	1	2	3	5	6	8
Pb	0.15	0.26	0.47	0.20	0.28	0.50
Cu	0.00	0.00	0.00	0.04	0.07	0.01
Zn	0.02	0.03	0.04	0.27	0.42	0.16
Ti	0.59	0.59	0.60	0.62	0.60	0.71
Al	10.8	10.7	10.8	11.4	11.6	11.2
Si	22.5	21.7	22.2	21.6	21.8	20.2
Ca	2.86	2.79	2.93	2.86	2.79	1.22
Fe	16.6	18.4	16.5	15.5	15.0	20.1
Ni ^(a)	0.12	0.06	0.10	0.09	0.12	0.07
Ba ^(a)	0.09	0.09	0.09	0.22	0.22	0.22
Sr ^(a)	0.07	0.07	0.09	0.13	0.15	0.06
Cr ^(a)	0.10	0.07	0.12	0.06	0.07	0.08

(a) Estimated by x-ray fluorescence methods.

Table 2-7. Total Chemical Composition for Spent Copper Slag Media

Element	Total Composition of Slag Sample (wt %)		
	4	7	9
Pb	0.84	0.52	0.92
Cu	0.94	0.69	0.56
Zn	3.75	3.25	3.15
Ti	0.36	0.37	0.40
Al	6.0	7.4	7.1
Si	14.1	15.5	16.1
Ca	6.58	5.36	4.43
Fe	23.6	23.1	23.4
Ni ^(a)	0.20	0.15	0.15
Ba ^(a)	0.19	0.13	0.17
Sr ^(a)	0.03	0.05	No data
Cr ^(a)	0.29	0.21	0.21

(a) Estimated by x-ray fluorescence methods.

Table 2-8. TCLP Results for Spent Coal Slag Media

Element	TCLP Result for Slag Sample (mg/L)					
	1	2	3	5	6	8
Pb	6.9	22.0	25.0	25.0	13.0	23.0
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	<0.003	<0.003	0.005	<0.003	<0.003	<0.003
Ba	0.50	0.60	0.30	0.40	0.40	0.60
Cd	0.022	<0.005	0.036	0.011	0.014	<0.005
Cr	0.41	0.25	0.33	0.02	0.02	0.10
Hg	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Se	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

Table 2-9. TCLP Results for Spent Copper Slag Media

Element	TCLP Result for Slag Sample (mg/L)		
	4	7	9
Pb	25.0	0.73	1.5
Ag	<0.01	<0.01	<0.01
As	<0.003	<0.003	<0.003
Ba	1.4	1.70	2.10
Cd	0.026	0.016	<0.005
Cr	0.10	<0.01	0.01
Hg	<0.0002	<0.0002	<0.0002
Se	<0.004	<0.004	<0.004

2.2 Characteristics of Other Similar Wastes

As part of the project, other wastes generated at Navy facilities with characteristics similar to ABM will be identified. Data on characteristics of the wastes and where/how they are generated by the Navy will be provided.

Wastes similar to ABM will be defined as a hard, granular matrix with a high silica and/or alumina content contaminated mainly with inorganics. Examples of such materials include:

- metals-contaminated soils
- casting sands
- catalysts
- ashes and condensed fumes
- slags
- construction and demolition debris
- refractory bricks
- metallurgical furnace dust.

2.2.1 Metals-Contaminated Soils

A variety of activities can contaminate soils with metals. The backstop at a firing range collects lead (possibly containing arsenic as a hardening alloy) and copper. Metal waste discharges from activities

such as plating and paint removal. Fugitive emissions or leachate from waste piles, landfills, or sludge deposits also can add undesirable metal constituents to soil.

Soils consist of weathered mineral grains and organic materials in varying proportions. Soils typically are heterogeneous and may be stratified due to historical variations during the soil formation process. Soil layers form as a result of interaction between the soil and groundwater, atmosphere, and vegetation. The properties of the upper layers are particularly affected by biological activity of plants and microorganisms. As a result, the surface soil properties are strongly influenced by soil chemistry, moisture content, and climatic conditions.

The wide variations in natural soil properties and contaminant levels encountered in site remediation cannot be overemphasized. Not only do soil and contaminant conditions vary from site to site, but wide ranges of conditions frequently occur within one site. The process or equipment selected to handle contaminated soils must be able to accept wide variations in soil conditions and contaminant levels.

Many systems are available for classifying soil type and constituents. Most of these classifications include particle size as the primary physical parameter. Typical classifications, in order of decreasing size, are:

- gravel
- sand
- silt
- clay

The organic content of soil can vary from less than 1% in dry, sandy soils to more than 20% in soils that are exposed to water much of the time. The chemistry of the organic portion of soils is complex. The soil organic content will consist of high-molecular-weight humic materials and lower-molecular-weight organic acids and bases. The high-molecular-weight humic materials have low water solubility and high affinity for metals. The humic and fulvic acid fraction account for most of the metal immobilization due to soil organic matter. These acids immobilize metals by complexation and chelation mainly due to acidic sites. The lower-molecular-weight organics tend to mobilize metals. These nonhumic materials form water-soluble complexes with metals resulting in more mobile species (Czupryna et al., 1989).

Other characteristics that help identify soil type and behavior include structure, color, density, type, and amount of organic and inorganic colloidal materials. Typical engineering properties, such as density and Atterberg limits, will indicate the handling properties of the soil. The solubility of metals in soil is controlled by factors such as pH, Eh, the ion exchange capacity, and the complexing and chelating effects of organic matter. Measurement methods and the significance of each of these factors have been described in several documents (Bodek et al., 1988; Cameron, 1992; Sims et al., 1984).

2.2.2 Casting Sands

Foundries use sand to make molds and cores to contain and shape metal during casting. The sand grains are held together with additives called binders. Mold-making techniques may use sand mixed with a small amount of clay and water or more complex binder systems such as silicates or organic resins such as phenolic-urethane polymers.

2.2.3 Catalysts

Catalysts used for industrial processes typically are in the form of a ceramic support carrying a small quantity of metal catalyst such as a chromium, nickel, or platinum group metal. The supporting ceramic often is a sphere of controlled particle size consisting mainly of alumina (Al_2O_3) and silica (SiO_2). In use, the catalyst becomes fouled with reactants or reaction products (Pavel and Elvin, 1994). Catalyst activity often can be recouped by thermal regeneration, but some of the particles break during the regeneration process. Once the catalyst particles become too small to be useful, they can become a waste disposal problem.

2.2.4 Ashes and Condensed Fumes

Fly ash is fine particulate waste collected from off-gas leaving processes such as smelting or coal combustion. Fly ash particles form in a high-temperature gas stream. At the typical combustion or processing temperature of about 2,900°F (1,600°C), the ash material is a molten sphere. As the particles cool, they retain a generally spherical shape. The particulate is collected by baghouses, electrostatic precipitators, or similar off-gas cleaning equipment. The particulate is mainly glassy, spherical silicates and aluminates material with particle sizes in the range of 4E-5 to 6E-3 in (1 to 150 micrometers [μm]) (Gera et al., 1991). The fine particulate may be removed from the off-gas cleaning equipment as either a dry powder or a water slurry and then be sent to a storage pile for subsequent disposal or recycling.

Fumes are very fine particulates produced during high-temperature metal processing. Volatile metals or metal oxides evaporate and recondense to form the fume. One common example is condensed silica fume, a fine particulate consisting of over 90% silica. Condensed silica fume is a byproduct of ferroalloy production. Metal impurities may impart a hazardous waste characteristic. The fume is an artificial pozzolan with a very high activity due to its small particle size and amorphous structure. Volatile metals such as cadmium and zinc also are prone to fume formation. The fine-particle fumes are difficult to transfer by conventional materials-handling techniques (Popovic et al., 1991).

2.2.5 Slags

Slag is a fused solid consisting mainly of inorganic oxides of silicon, iron, and calcium with metallic impurities. Slag is a typical waste product from pyrometallurgical metal processing. The slag composition depends on the feed material source and the process used. Slags generally contain silica (SiO_2) as the main constituent along with fluxing salts (e.g., calcium and magnesium) and metal impurities from the ore.

Density, porosity, and leach resistance are the main properties considered in evaluating slag as a contaminated matrix. These properties vary depending on the method of producing the slag. The form of slag produced depends on the conditions used for cooling. Testing has indicated that faster slag cooling is important for reducing the mobility of metals. The general categories of slag are air-cooled, expanded, and granulated.

2.2.6 Construction and Demolition (C&D) Debris

C&D debris is bulky waste resulting from land clearing, building new structures, and remodeling or tearing down old structures (von Stein, 1993). The approximate overall average content of debris from demolishing structures in the United States is 53.8% concrete, 21.2% brick, 22.0% wood, 2.7% iron and steel, and 0.22% glass. Small amounts of a wide range of substances, including copper, lead, aluminum, plastic, paper, gypsum board, and asbestos, make up the rest of the debris. Crushed C&D debris usually has a soil or rocklike appearance and consistency. Concrete in C&D debris may contain steel or iron

reinforcing bars which can complicate processing the waste for reuse. Although C&D debris usually is not hazardous waste, the potential for hazardous or toxic contaminants should not be ignored. Possible sources of contaminants in C&D debris include:

- asbestos used for insulation or structural applications
- creosote, pentachlorophenol, or chromated copper arsenate preservatives in wood
- polychlorinated biphenyls (PCBs) in electrical components
- metals (particularly lead) in paint pigments.

2.2.7 Refractory Bricks

Refractory bricks are high-performance ceramic materials used to line high-temperature processing equipment. Refractory bricks are made from chromite or similar chromium oxide materials. The bricks deteriorate in use and are replaced periodically during furnace maintenance (Martin et al., 1987). Many refractory bricks contain percentage levels of chromium and can exhibit the D007 chromium toxicity hazard characteristic. The bricks also may become contaminated by process materials during use.

2.2.8 Metallurgical Furnace Dust

In production of steel in electric arc furnaces (EAFs), feed materials are charged into a refractory-lined furnace and melted by an electric current arcing between electrodes through the metal feed. EAFs accept a high proportion of scrap in the feed. The scrap steel is often galvanized, coated, or plated to improve its function. The most common surface treatments are zinc galvanizing, lead terne coating, and cadmium plating. Each of these plating metals tends to partition to the vapor phase as a fume. The fume condenses and is then removed by a dry filtration or wet scrubbing operation. The EAF process removes many metal impurities from the scrap by volatilization. Because of the ability to remove impurities, the EAF processes almost 100% scrap (with a maximum of 30% galvanized scrap feed). The high level of scrap feed to the EAF causes elevated levels of zinc, cadmium, or lead in the fumes from the furnace. Due to the presence of these metals, emission control dust/sludges from EAFs are a RCRA-listed waste (K061).

The composition of the dust formed varies directly with the type of steel being produced and the constituents being volatilized from the furnace. Specifications for carbon steels are generally less restrictive than specifications for high-alloy steels. Carbon steel making can start with an initial charge of scrap containing higher loadings of plating and other impurities. Due to the higher scrap loading, the dust generated from the production carbon steels may contain more lead and other impurities than the dust

Table 2-10. Typical Composition Ranges for EAF Emission Control Dust

Element	Metal Content Range for Specialty-Steel Producers (weight %)	Metal Content Range for Low-Alloy Producers (weight %)
Cadmium	0.04 to 0.08	0.01 to 0.07
Lead	0.54 to 1.36	0.21 to 45.28
Zinc	2.27 to 8.52	0.79 to 3.49
Nickel	1.83 to 3.60	0.13 to 0.24
Iron	22.96 to 25.81	4.07 to 43.09
Chromium	7.64 to 11.71	0.01 to 3.43

Source: Hanewald et al., 1992.

from the production of specialty, stainless, and alloy steels. Dust from making higher alloy steels will contain more chromium and nickel. Typical concentration ranges for EAF dust from specialty-steel and low-alloy producers are shown in Table 2-10.

3.0 RECYCLING AND REUSE OPTIONS

This section describes the operating features and applications of recycling and reuse options for ABM and similar wastes. The recycling methods are arranged generally in the order of decreasing value of the product produced. Methods to recycle spent ABM are organized into the following groups:

- reconditioning and reuse of spent ABM
- processing to convert spent ABM into high- or medium-value ceramic products
- using spent ABM as a raw material in portland cement
- using spent ABM as aggregate in portland cement concrete
- using spent ABM as aggregate in asphaltic concrete
- using spent ABM as a basic construction material
- processing to convert spent ABM into low-value ceramic products
- using spent ABM as a flux-forming addition in a smelter.

3.1 Reconditioning and Reuse of Spent Abrasive

This section describes methods to process and reuse spent ABM. The spent ABM can be cleaned using physical separation to remove fines and/or hard metal or metal oxide particles and then reused.

3.1.1 Description of Recycling Option

Reclamation of ABM implies collecting the ABM after use and processing to remove undesirable components in the ABM. Reclamation of spent ABM applies simple unit operations, but there are challenges to successful implementation. Collecting and storing the spent media requires equipment and procedures not used in normal blast cleaning done outdoors on large structures such as ships. Once the spent ABM is collected, several processing steps are needed to return the material to its original quality to allow reuse.

Collection and handling of spent ABM can be conducted with minimal concern about adding extraneous contaminants when the spent ABM is to be discarded. Spent ABM collected for disposal usually contains a high proportion of soil and may contain general site trash including paper, cloth, or plastic scraps and small metal parts (e.g., bolts, screws, and brackets). Additional care must be taken to collect the spent ABM for reclamation.

A wide variety of undesirable components including debris from the work area, ABM fragments, and paint particles and contaminants removed from the hull are intermixed with the spent ABM. When the ABM impacts the surface being cleaned, some of the media fracture, producing fine particulates that must be removed during the reclamation process. A high proportion of fines will:

- reduce the effectiveness of coating removal
- increase dust generation when the grit is reused.

Small bits of steel and metal oxide are cut away from the ship hull during the blast cleaning process. If these hard particles are not removed by the reclamation process, they will strike the surface being cleaned creating high residual stress in small areas. These stressed spots can be points of initiation of fatigue fractures or increased corrosion.

Simple screening is unlikely to clean the spent ABM sufficiently to allow reuse. Because the contaminants in the ABM have a wide range of physical and chemical properties, successful reclamation

processing requires more sophisticated methods. Screening to remove oversize debris is always the first step. This first simple cleanup is followed by various combinations of magnetic separation, water-assisted beneficiation, and thermal treatment to produce an acceptable reclaimed ABM product.

3.1.2 Advantages of Recycling Option

Reclaiming spent ABM for reuse provides reduction in resource consumption with minimum transportation and handling. Onsite recycling is the next level in the U.S. EPA's waste reduction hierarchy, when waste production cannot be prevented at the source.

3.1.3 Limitations of Recycling Option

Reclamation requires the use of a tough, fracture-resistant ABM which increases the unit cost, and purchasers often prefer to minimize even the initial cost. Sand, the cheapest media, is unsuitable for reclamation. Slag-based media cost more per ton but will survive a few cycles of reuse, and garnet media, which cost even more, can be reused for many cycles. The number of reuse cycles attained in practice will depend on many factors including the air pressure used to apply the ABM, the type of coating removed, and the worker's experience level.

A significant fraction of undesirable materials (e.g., ABM fragments, paint chips, and hard particles) must be removed from the spent ABM. These undesirable components will need to be managed as waste and may be listed as hazardous waste under RCRA.

The possible presence of hard particles in the reclaimed ABM increases the concern for creating high stress points in the ship hull when the ABM is reused.

The possible presence of impurities in the reclaimed ABM increases the concern for high airborne contaminant levels in the work areas and for contaminating the ship hull when the ABM is reused.

3.1.4 Example Applications

3.1.4.1 Thermal Processing of Spent ABM. The U.S. Navy and the Institute of Gas Technology (IGT) have been developing and testing thermal processing to reclaim spent ABM. The technology is an extension of a fluidized-bed coal combustion system developed by IGT that has been applied to the reclamation of foundry sand. The fluidized-bed ABM treatment system is illustrated in Figure 3-1.

The spent ABM is conveyed from a storage pile to pass through a grizzly and a 0.5-in (12-mm) vibrating screen to remove oversized debris and then through a magnetic separator to remove ferromagnetic particles. After the initial cleaning, the spent ABM is fed by a screw conveyor into the top of the fluidized-bed calciner. A mixture of gas and air is introduced into a pipe in the bottom center of the bed. The air and natural gas burn directly in the bed to heat the spent ABM to 1,200°F to 1,600°F (650°C to 870°C) and to oxidize the organic portion of paint chips to CO₂, H₂O, and metal oxides.

The gas flow in the calciner provides mixing and size classification in addition to the heating action. The ABM bed is well agitated and heated by the burning gas to ensure good combustion of the paint chips and removal of the fine particulates. Metal oxides from the burned paint chips and undersized particles of broken ABM are entrained in the gas stream and lifted out of the calciner. The clean ABM flows down along the sloped grid and exits the bottom of the calciner past the incoming air and gas.

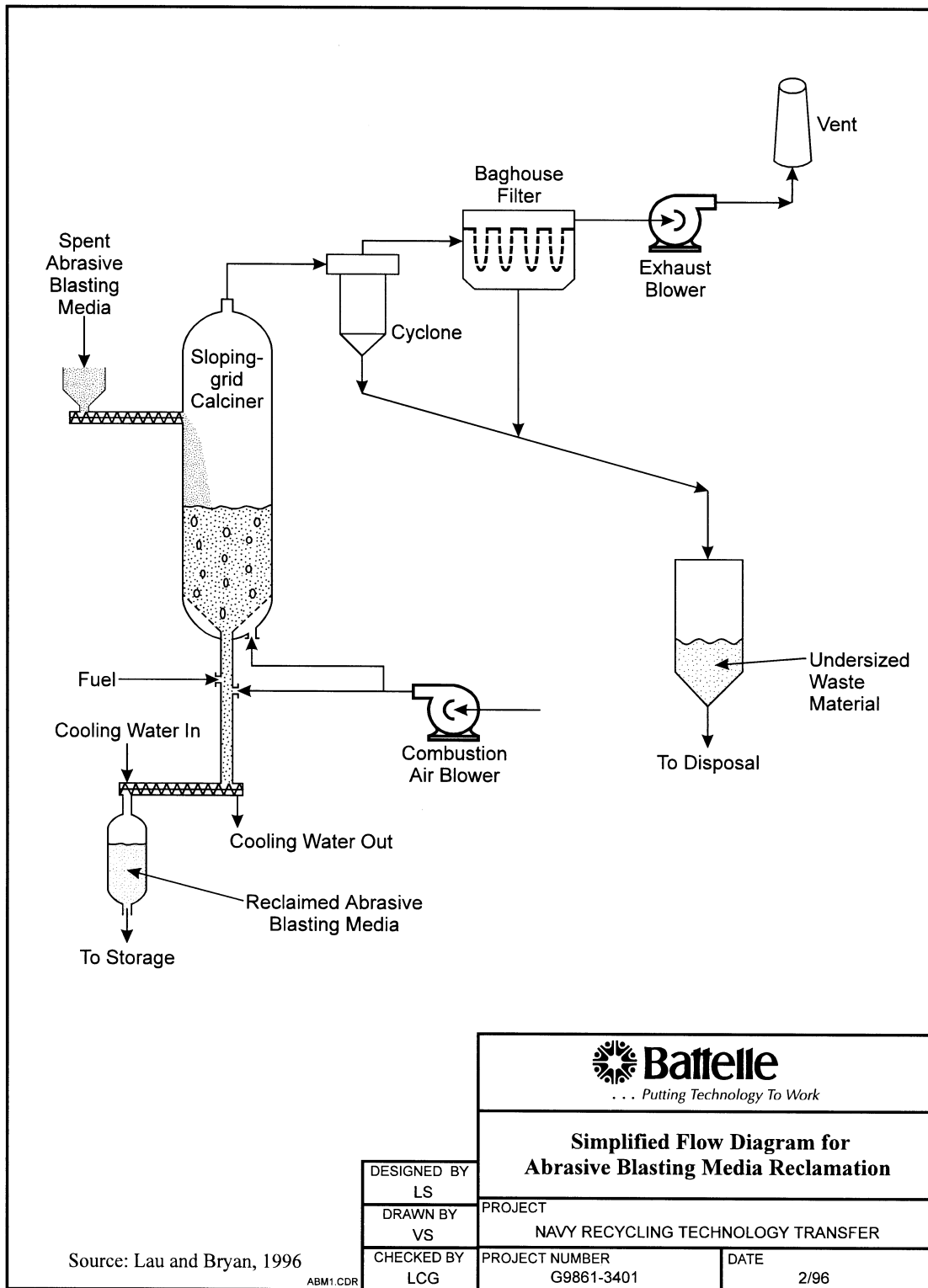


Figure 3-1. Simplified Flow Diagram of Abrasive Blasting Media Reclamation

The clean ABM is moved from the bottom of the calciner through a water-cooled screw conveyor and placed into storage for reuse. The process can reclaim between 80% to 90% of the spent ABM.

The metal oxides and fine particles are removed from the off-gas for disposal. Off-gas from the calciner is cooled with a water spray and then passed through a cyclone separator and bag filter to collect particulates for disposal.

3.1.4.2 Physical Reclamation of Spent ABM. Pittsburgh Mineral and Environmental Technology owns and operates mobile units for recovery of spent abrasive contaminated with paint chips containing hazardous metal contaminants. The most common application is treatment of abrasive used to remove lead-based paints from bridges, overpasses, and other steel highway structures. The spent abrasive is a complex mixture of abrasives, paint chips, steel, and rust. The process is reported to separate the spent abrasive stream into three reusable fractions:

- paint chips
- coarse abrasive
- undersized abrasive.

The lead-bearing paint chips can be sent to a lead smelter for reprocessing, the coarse abrasive is reused, and the undersized fines are used as feed for other ceramic products such as bricks.

The abrasive processing unit is mobile and can be set up at the paint removal site to process material at the rate of about 2 to 5 tons (1.8 to 4.5 metric tons) per hour. Spent abrasive is screened to remove coarse materials such as debris and larger paint chips. Magnetic separation then removes the steel particulates and other ferromagnetic materials. The nonmagnetic portion is fed onto a gravity separation table to separate the fine particulate from the coarse abrasive based on the apparent density of the particles (as determined by their respective gravity, shape, texture, and size). The coarse fraction can be reused as abrasive. The fine fraction is further treated by electrostatic separation based on differences in surface conductivity to separate the paint chips from the fine abrasive particles. The paint chips can be fed to a metal smelter, and the fine abrasives can be fed to a brick-making process. The process is reported to be accepted by the U.S. EPA Region III and the Pennsylvania Department of Environmental Resources as a recycling process for abrasive contaminated with lead-bearing paint chips (Gilbert and Weyand, 1990).

3.1.4.3 Soil Washing to Clean Spent ABM. Westinghouse Electric Corporation has developed a cleaning system for spent sandblasting abrasive used to remove lead-containing paint. The technology is based on Westinghouse research in soil washing. The system is reported to operate at a throughput of 20 tons (18 metric tons) per hour. Abrasive is cleaned with water-based leachates, which are continuously recycled in the soil washing system. The end products are cleaned abrasive, which is reported to be suitable for reuse, and the leach solution, which can be treated by chemical precipitation or membrane separation.

3.2 Use Spent Abrasive as a Raw Material in Ceramic Manufacture

This section describes ways to use spent ABM and similar wastes as a raw material in making medium- or high-value ceramic products. Ceramic products made from ABM or similar wastes will be competing with products in the Standard Industrial Classification (SIC) group 32 (OMB, 1987). Economic characteristics indicating the size of the market for products in SIC group 32 are summarized in Table 3-1.

Table 3-1. Summary of Ceramic Product Market Characteristics

Industry/SIC	1987		1992
	Number of Establishments in SIC	Total Value of Shipments (\$ million)	Total Value of Shipments and Inventory (\$ million)
Stone, clay, and glass products/32	16,166	61,477	62,479
Flat glass/321	81	2,549	2,082
Glassware /322	522	8,339	9,055
Processed glass products/323	1,432	5,429	6,955
Cement/324	215	4,335	4,035
Structural clay products/325	598	2,915	2,864
Pottery/326	1,006	2,416	2,752
Concrete, gypsum, and plaster products/327	9,814	24,427	23,053
Cut stone and stone products/328	745	841	1,007
Misc. nonmetal mineral products/329	1,753	10,226	10,677

Source: U.S. Department of Commerce (1995, Table 1246).

The SIC group 32 has not been a strong growth or profit area for several years. The total value of shipments increased only 1.6% between 1987 and 1992. Most or all of this increase can be accounted for by inflation. Profit for each dollar of sales in 1990 was 1.8 cents. The industry showed a loss of 0.7 cent per dollar of sales in 1992 but rebounded to show a profit of 3.4 cents per dollar of sales in 1993. For comparison, the average profit for all manufacturing concerns was 5.4 cents per dollar of sales in 1993 (U.S. Department of Commerce, 1995, Table 890).

3.2.1 Description of Recycling Option

Spent ABM and similar wastestreams consisting predominantly of silica and/or alumina with low levels of metal contaminants can be processed thermally to form glass or ceramic products or be used as raw materials in ceramic manufacture. The glass or ceramic matrix can effectively immobilize many metal impurities. The metal contaminants may even impart desirable properties such as coloration or increased hardness to the product.

Formation of ceramic products may be accomplished by either sintering or melting. In both processes, prepared waste material is heated to form the ceramic. Most thermal treatment processes require feed material to be within a narrow particle size range. Size reduction and/or pelletization are usually needed to obtain the required size.

In sintering, the waste is prepared by mixing with clay or other silicates and possibly water and additives. The mixture is pressed or extruded to form bricks, pellets, or other shapes. The formed products are treated at high temperature but below the bulk melting temperature where particles join or sinter to form a solid ceramic piece.

Vitrification processes also require feed preparation. The chemical additions and mixing may be used to promote oxidation-reduction reactions to improve the properties and stability of the final product. Silica sources such as sand or clay may also be needed. Vitrification processes operate by heating the pretreated waste to melting temperatures. The molten treated waste flow exits from the melter into a waste-forming or quenching step. The melt can be formed in a metal- or sand-coated mold to form a monolithic product or quenched in a water bath to produce a frit. Vitrification to form low-value aggregates, as described in Section 3.7, uses the same basic approach but typically starts with wastes that contain complex mixtures of contaminants.

Gases released from the thermal treatment unit are processed through an emission control system. Particulates may form due to carryover, metal fuming, or anion fuming. The particulates are removed by knockout boxes, scrubbers, and/or venturi separators. Particulates are separated from the scrubbing fluid by filtration and are returned to the treatment system. Acid gases, such as sulfur dioxide from sulfates, are removed by scrubbing with sodium hydroxide.

A wide range of high- to medium-value products could be made from ABM or similar silicate or aluminate wastes. Possible products include:

- ceramic tile
- finished and rough dimension stone
- brick and structural clay items
- frit.

Ceramic tiles are thin ceramic squares or rectangles, usually with a decorative finish on one surface used for appearance in architectural applications.

Dimension stones are block, panel, or curvilinear shapes used for appearance and/or structural functions. The stone shape can range in size from the base of a pen and pencil set to large building stone.

Brick and tile shapes are made from fired clay and used for load bearing or other applications (e.g., non-load-bearing fire walls, sound absorption walls, or drainage tiles). These ceramic items generally are simple rectangular or cylindrical shapes with moderate surface finish and size tolerance requirements.

Frit is a raw material for ceramic manufacturing. A waste can be vitrified to destroy organic impurities and improve its physical properties and then further processed in an existing manufacturing plant to form products such as refractory fibers or abrasives.

3.2.2 Advantages of Recycling Option

Thermal treatment to produce useful products from wastes has the potential to reduce negative effects on human health and the environment over the product's life-cycle and to reduce the costs for management of wastes (Carter and Tsangaris, 1995). The main purpose for using the vitrification process is to convert a material that would have been a waste into a value-added product. Using waste material to replace raw materials in product manufacture decreases demand on resources and reduces the volume of

waste discharged. In addition to value created by the product, costs for treatment and disposal are avoided. The end user of the resulting ceramic product may be closer or more distant, so transportation may have a positive or negative effect on the economics of waste vitrification depending on the location of the vitrification plant and the user.

The high-temperature vitrification or sintering process causes significant changes in the physical or chemical form of the matrix and the contaminants. Organic constituents such as resin in paint chips are oxidized to their mineral components. Metal contaminants are incorporated into a durable, leach-resistant mineral matrix.

3.2.3 Limitations of Recycling Option

Contaminants in the waste product will change the hardness, toughness, color, or texture of ceramic products which may reduce product performance or acceptance. Only selected wastestreams can be converted into high-value ceramic products. To provide a high-value product such as decorative finished dimension stone or frit for making high-performance refractories, the initial wastestream must contain a limited number of contaminants. For example, hydroxide sludge from treatment of plating or etching baths containing a single metal contaminant is converted by vitrification on a commercial scale to high-value products (Hazardous Waste Consultant, 1990). Purely cosmetic features usually are not strong determinants of product acceptance for the structural products but may still reduce acceptance in some applications. For example, the dark or earth tones that occur in vitrified products containing a wide range of metals are undesirable in applications where the item needs to be visible, such as railings, parking lot stops, or road barriers.

The process is capital- and energy-intensive, but the product value and avoided disposal costs will contribute to the economic viability of the option.

Volatile metals such as arsenic, mercury, or beryllium are difficult to treat and can be present only at low concentrations. Wastes containing arsenic will require some combination of pretreatment, special processing conditions, and/or off-gas treatment systems to minimize arsenic volatilization. If reducing conditions can occur in the melt, cadmium, lead, and zinc can vaporize and enter the off-gas stream (Hollander et al., 1995).

The product potentially would be used in close proximity to the general public and thus would be required to meet high standards of contaminant immobilization and performance.

3.2.4 Example Applications

3.2.4.1 Using Abrasive Blasting Media to Make Bricks. Spent ABM is an ideal candidate for beneficial reuse in the manufacture of structural fired clay products, e.g., bricks. The U.S. Navy, David Taylor Research Center in Annapolis, Maryland, has been studying this alternative for the past several years. The bricks are produced using spent ABM to meet the specifications for strength and absorption, while metals are incorporated into a chemically stable, complex silicate phase during brick firing. Data collected thus far indicate that metal leachability in the final clay product increases with decreasing particle size of the spent ABM (Thomas, 1992).

Pittsburgh Mineral and Environmental Technology performed a study of beneficial reuse of ABM from bridges for the Pennsylvania Department of Transportation. The study concluded that using spent ABM to replace sand in brick making was the most promising option. Test bricks were made with 10%, 20%, and 40% of the normal brick mix. Unprocessed ABM gave poor results. However, when the ABM

was crushed and screened to reduce particle size to below 20 mesh, the test bricks were acceptable (Weyand and Sutton, 1990).

3.2.4.2 Using Foundry Slag to Make Bricks. Granulated slag from cast iron production was ground to give a Blaine specific surface area of 100 ft²/oz (3,200 cm²/g). The ground slag was used in combination with lime and sand to produce 1.6-in (4-cm) cubes for testing. The reported compressive strength ranged from 1,860 to 2,480 psi (12.8 to 17.1 MPa) (Malolepszy et al., 1991).

3.2.4.3 Using Incinerator Ash to Make Bricks. Research has been reported on the properties of brick made with incinerator-derived ash used in combination with cement and limestone screenings. The ash was produced by a refuse-derived-fuel facility. Two series of tests were carried out with bricks formed with 20% and 40% ash. In the two series, the cement content varied from 4% to 10% and the water content varied from 2% to 8%. The remainder of the brick composition was normal limestone sand. The reported compressive strength for the 10% cement, 40% ash, and 8% water case was 7,500 and 6,800 psi (52 MPa and 47 MPa) for air-dried and soaked curing conditions, respectively. The compressive strength increased with increased cement and ash content (Ali et al., 1992).

3.2.4.4 Using Spent Catalysts to Make Bricks. Cherokee Environmental Group of Sanford, North Carolina processes nonhazardous spent catalysts for use as aggregate in brick making. Catalysts are crushed and size-graded to form an alumina/silica sand which replaces sand in brick making.

3.2.4.5 Metal-Containing Waste Sintering. The Ceramic Bonding, Inc. of Mountain View, CA provides a treatment method to convert waste into an alumina-silicate ceramic used to physically and chemically immobilize metal contaminants. The waste is mixed with a proprietary alumina silicate material and extruded into pellets. The pellets are fired at 2,000°F (1,090°C) to form a ceramic solid called Armorite™. This material reportedly is leach-resistant and is suitable for use as a ceramic making raw material or as a construction aggregate.

Waste materials amenable to treatment include filter cakes, foundry sand, ash, and sludge. The process treats inorganic wastes containing cadmium, chromium, cobalt, copper, lead, nickel, vanadium, or zinc. Metals that will volatilize under process conditions, such as mercury or arsenic, cannot be treated. Ceramic Bonding is reported to be planning to offer processing of F006 waste and some site remediation wastes as a RCRA-exempt recycler.

3.2.4.6 Metal-Containing Waste Vitrification. Pollution Control Systems of Dublin, Ohio markets a process to recycle metal-contaminated sludge wastes into feed material for architectural, abrasive, and refractory ceramic products. The company installs and operates a process system at the waste generator's site. The U.S. EPA is reported to have accepted the process as a recycling process exempt from RCRA permitting based on testing and performance data. Applicable waste types include D characteristic wastes and F and K listed wastes such as F006 and K061.

The process, as illustrated in Figure 3-2, involves three primary components:

- mixing
- vitrification
- off-gas treatment

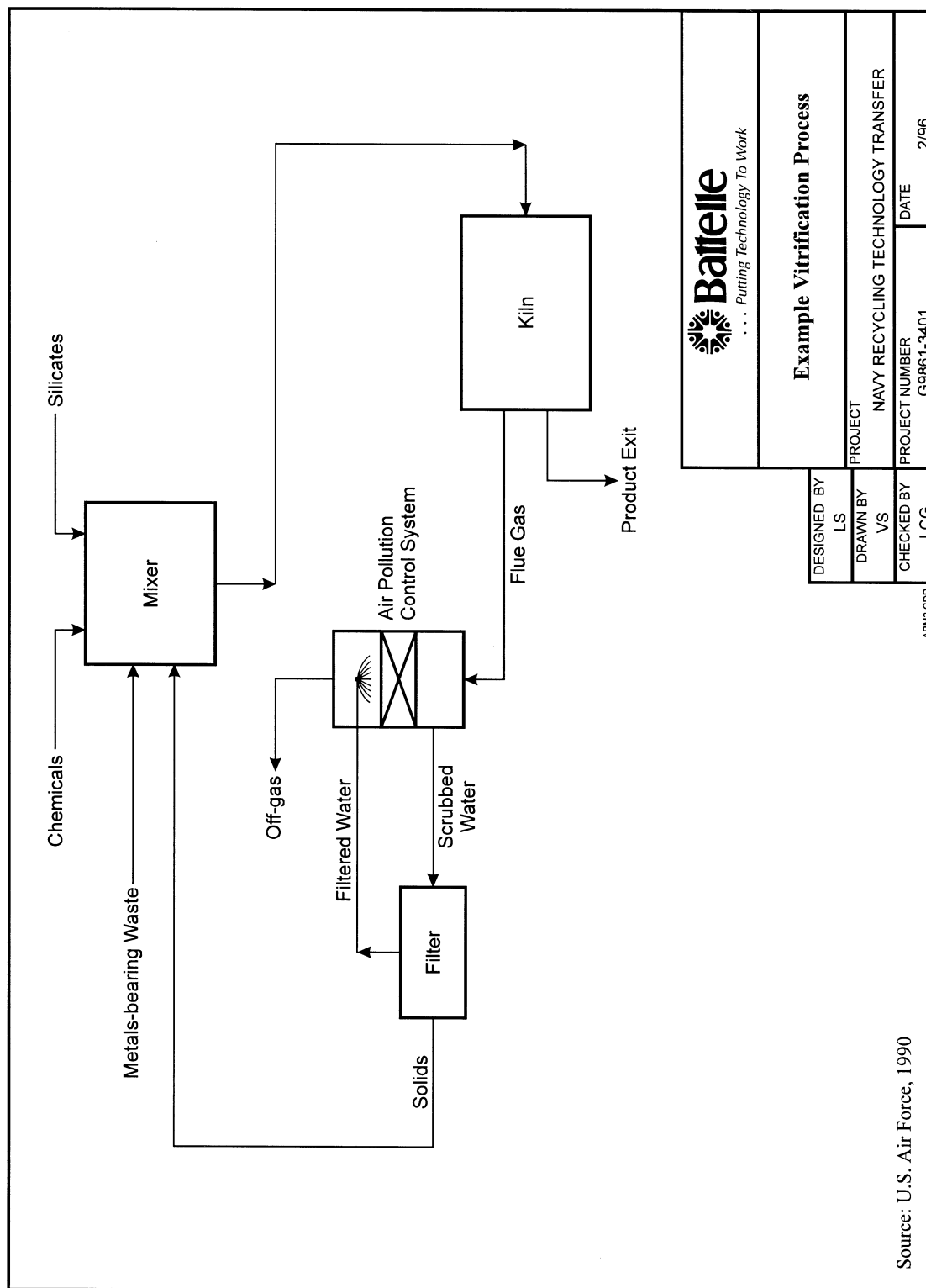


Figure 3-2. Example Vitrification Process.

All incoming generator materials are processed on a batch basis. Prior to entering the reactor, each batch of waste is tested to determine requirements for raw materials addition. The waste is typically a sludge to which water and chemicals are added. The chemical additions and mixing promote a series of oxidation-reduction reactions to improve the properties and stability of the final product. Following the reaction phase, silica sources such as sand or clay are added. The mixed materials are transferred to a surge tank to provide continuous feeding to the vitrification operation.

Vitrification operates continuously with blended/reacted feed entering the vitrifier where it is heated to form a molten mass. The material travels through the vitrification unit to an exit overflow. The operating temperature and residence time of the vitrification unit are determined by laboratory analysis. The molten treated waste flow exits from the melter into a waste-forming or quenching step. The melt can be formed in a sand-coated mold or quenched in a water bath depending on the type of product needed. The resulting ceramic material is packaged for shipment to end users.

Gases released from the vitrification unit are processed through an emission control system. Particulates may form due to carryover, metal fuming, or anion fuming. The particulates are removed by knockout boxes, scrubbers, and/or venturi separators. Particulates are separated from the scrubbing fluid by filtration and are returned to the treatment system. Acid gases, such as sulfur dioxide from sulfates, are removed by scrubbing with sodium hydroxide to form sodium metasilicate. The sodium metasilicate reportedly is collected and sold.

3.2.4.7 Using Fly Ash to Make Clay Products. Fly ash from a coal combustion, steam-generating plant was used in combination with clay, cement, or lime to make extruded bricks. The resulting bricks were tested for shrinkage, weight loss, tensile strength, compressive strength, and mineralogy. Addition of fly ash was reported to improve the quality of the bricks due to the grain size, shape, and the pozzolanic activity of the fly ash (Temini et al., 1991).

3.3 Use Spent Abrasive as a Raw Material in Portland Cement Manufacture

This section describes use of spent ABM and similar waste as a raw material in making portland cement. Cement is made from a mixture of limestone, sand, and clay prepared and burned to form clinker which is then ground. The expected U.S. production of portland and masonry cement in 1995 is 87,300,000 tons (79,300,000 metric tons). Portland cement makes up about 96% of the total U.S. cement output (Solomon, 1995a). Many sandlike waste materials can provide useful calcium, silica, alumina, or iron inputs for cement makers. Due to the large volume of cement produced, significant quantities of spent ABM can be consumed as replacements for cement raw materials and at the same time conserve resources. The European cement industry reports that use of secondary raw materials, such as granulated blast furnace slag and coal combustion fly ash, has reduced mineral and energy resource consumption (Lawton, 1992).

3.3.1 Description of Recycling Option

Manufacture of hydraulic cement offers possibilities for recycling of contaminated waste materials. Making cement requires a significant input of energy and raw materials. Petroleum-contaminated soils are used as input to cement kilns by a variety of companies. Petroleum-contaminated soils supply both heating value and a silica source (U.S. EPA, 1992, EPA/600/R-92/096). Opportunities also exist for using nonhazardous metals-contaminated solids to make cement, particularly when the waste has a high alumina or iron oxide content.

Portland cement is made by heating mixtures containing lime, silica, alumina, and iron oxide to form clinker which is then ground. About 3% to 5% of calcium sulfate, usually as gypsum or anhydrite,

is added during grinding of the clinker. The gypsum aids in the grinding process and helps control the curing rate of the cement product (Collins and Luckevich, 1992). The gypsum is intermixed during grinding of the clinker. The main constituents of portland cement are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF).

Specifications for limestone feed for cement making require that the calcium carbonate ($CaCO_3$) content be greater than 75% and the magnesium carbonate ($MgCO_3$) content be less than 3%. Because the raw materials need to be finely ground, chert nodules and/or coarse quartz grains are undesirable (Tepordei, 1993b).

Raw material burning typically is done in a rotary kiln. The kiln rotates around an inclined axis (see Figure 3-3). The raw materials enter the raised end of the kiln and travel down the incline to the lower end. The kiln is heated by combustion of coal, gas, or oil injected at the low end of the kiln. As the raw materials move through the inclined, rotating kiln, they heat to a temperature greater than 2,600°F (1,430°C).

The residence time for solids is 1 to 4 hours, and the residence time for gases is about 10 seconds. The high temperature causes the following physical and chemical changes (U.S. EPA, 1982, EPA/600/2-82/013):

- evaporation of free water
- evolution of combined water
- evolution of carbon dioxide from carbonates
- partial fusion of the feed materials
- reactions among lime, silica, alumina, and iron to form the clinker.

During burning, lime combines with silica, alumina, and iron to form the desired cement compounds. The heating results in a product called clinker. Clinker consists of a granular solid with sizes ranging from fine sand to walnut size. The clinker is rapidly cooled, mixed with additives such as gypsum, and ground to a fine powder to produce the final cement product.

The American Society for Testing and Materials (ASTM) specifies five basic types of portland cement. Type I is intended for use when the special properties of the other types are not required. Type IA is for the same uses as Type I where air entrainment is desired. Air entrainment is a technique to improve the freeze/thaw resistance of the concrete and reduce the mix viscosity without increasing water. Type II is another general-use cement but offers decreased heat generation during curing and increased resistance to damage from sulfate salts in the soil. Type IIA is similar to Type II but is intended for use where air entrainment is desired. Type III is formulated to maximize early strength production. Type IIIA is the air entrainment version of Type III. Type IV is intended for use where the heat generation must be minimized. Type V is for use when sulfate resistance is desired. The main constituents of portland cement typically are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF). Example compositions for the types of portland cement are shown in Table 3-2.

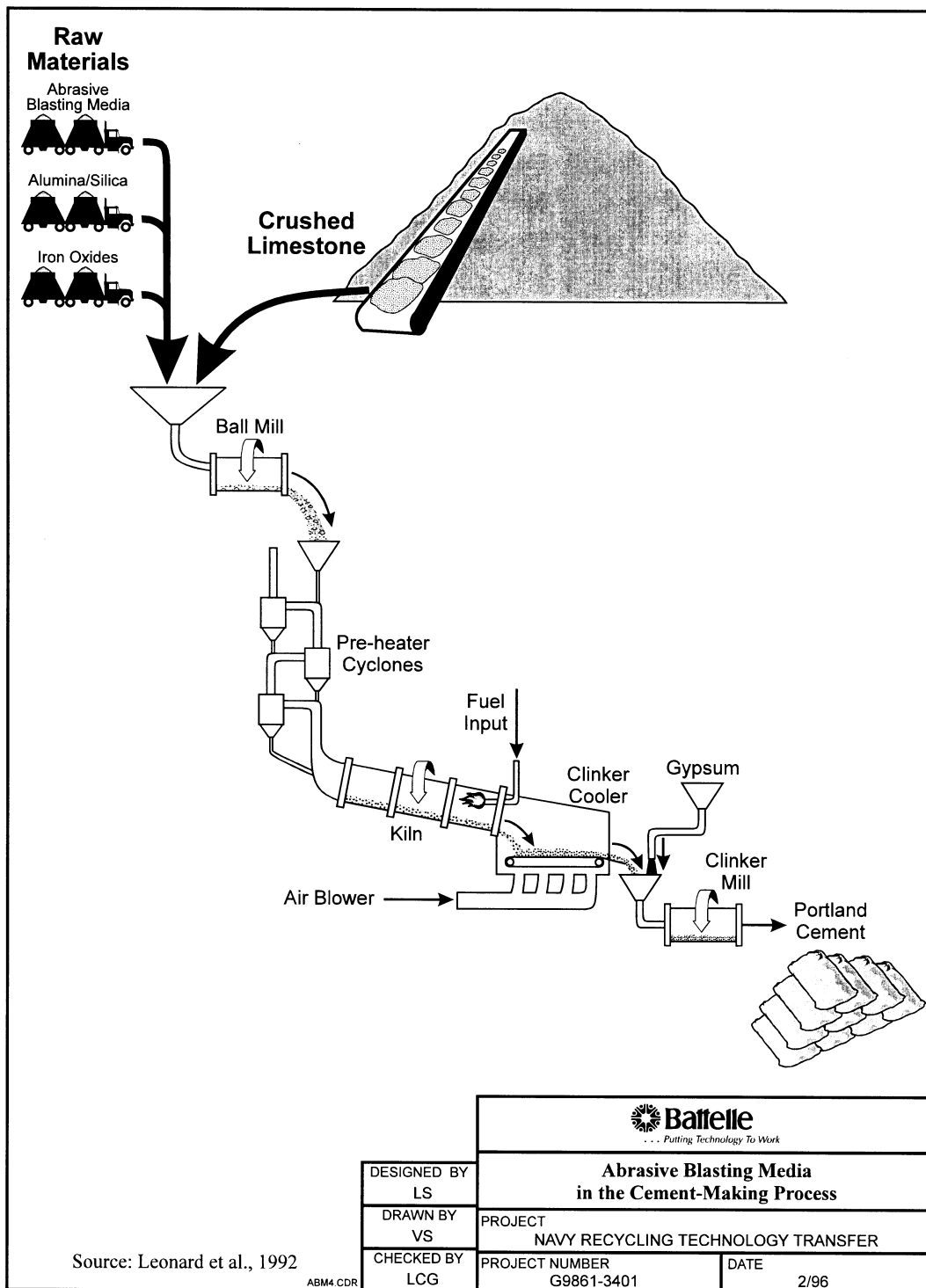


Figure 3-3. Abrasive Blasting Media in the Cement-Making Process.

Table 3-2. Examples of Compositions of Portland Cement Types

Cement Type	C₃S (wt %)	C₂S (wt %)	C₃A (wt %)	C₄AF (wt %)
I and IA	49.6	24.0	11.0	8.0
II and IIA	40.9	34.4	5.6	12.9
III and IIIA	59.3	14.1	9.3	7.9
IV	25.3	51.5	4.9	11.6
V	41.0	39.0	3.7	10.0

Source: Bogue, 1955.

3.3.2 Advantages of Recycling Option

Cement kilns have the capacity to recycle large quantities of waste. The kilns are widely distributed throughout the country, so long shipping distances can be avoided in many cases. For example, there are 11 cement manufacturers currently operating 20 portland cement kilns in the state of California. In 1989 alone, these operations reported the cumulative production of more than 10,400,000 tons (9,400,000 metric tons) of cement clinker. Due to gaseous losses during the calcining reaction, about 13,500,000 tons (12,250,000 metric tons) of mineral feedstock was required to generate the cement. Therefore, if only one tenth of 1 percent of the required feedstock for each of these kilns were dedicated to recycling of metal-bearing wastes, up to 13,500 tons (12,250 metric tons) of hazardous waste could be diverted from landfill disposal in just the state of California each year (Leonard et al., 1992).

Spent ABM and similar wastes also are good candidates for recycling as replacements for cement raw materials. Wastes high in alumina (such as bottom or fly ash, ceramics, and aluminum potliner) or iron (e.g., slag ABM, iron mill scale, foundry waste) are particularly good candidates. Silica and calcium also are beneficial ingredients, but these usually are provided in sufficient quantities by the quarry rock and therefore are not in as much demand.

Cement kilns provide high operating temperatures and long residence time, which cause significant changes in the physical and chemical form of the matrix and the contaminants. Organic contaminants are oxidized to their mineral components. Metal contaminants are incorporated into the portland cement matrix.

The high alkali reserve of the cement clinker reacts to form alkali chlorides (sodium, potassium, calcium), preventing evolution of acidic vapors in the off-gas. However, the chloride content of the wastes must be limited to avoid excessive kiln dust production. Most of the alkali chlorides vaporize and increase the quantity of kiln dust. Kiln dust containing a high proportion of alkali chlorides cannot be recycled to the cement kiln because soluble chlorides alter the setting rate of the cement product.

3.3.3 Limitations of Recycling Option

Recycling into portland cement is applicable to only certain types of wastes, based on chemical composition, contaminant levels, and other criteria (Bouse and Kamas, 1988a; 1988b):

- Aluminum, iron, and sometimes silica are the primary constituents which the kiln operator needs to purchase to supplement the naturally occurring concentrations in the quarry rock. Ores typically comprise 40 to 50% by weight of these constituents.

Therefore, waste materials should contain at least 20% or more of these constituents to be attractive substitutes for the ore materials.

- Combustion to heat the raw materials and decomposition reactions during formation of cement clinker generate large volumes of off-gas, which must be controlled and cleaned.
- Elevated concentrations of Na, K, S, Cl, Mg, and Ba can degrade the quality of cement or increase the volume of kiln dust waste produced. The plant chemist will be the final authority on whether a given waste material is compatible with the mix design.
- Recycling operations should be designed to avoid significant risk due to metals concentrations in the clinker or off-gas. Total metals concentrations in the recycled wastes should in general be <1%, and the clinker should be tested to ensure that the metals present are not highly leachable. Waste with highly toxic and volatile metals such as As or Hg should not be recycled in this manner.

Cognizant regulators should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c, Definition of Solid Waste). In most cases, special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions or policies. Nonhazardous silicate and aluminate wastes are used as raw material substitutes in portland cement manufacture on a commercial scale. Using wastes containing RCRA metals may be possible, but commercial application is limited by the requirements of the Boiler and Industrial Furnace regulations.

3.3.4 Example Applications

3.3.4.1 Using Spent Abrasive Blasting Media to Make Cement. The Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California, along with Southwestern Portland Cement Co., Mare Island Naval Shipyard, Radian Corporation, and Battelle, have been studying the recycling of spent ABM as a raw material for the manufacture of portland Type I cement for construction purposes. The ABM is a silicate slag containing moderate levels of iron (Fe) and replaces some of the iron ore that normally is used in cement manufacture. The silica and alumina in the ABM are also useful ingredients in the cement product.

The spent copper slag ABM was hazardous in the state of California because of its Cu content, but is not classified as a RCRA hazardous waste. Consequently, this recycling demonstration was conducted under a Research & Development (R&D) variance issued by the California EPA.

During the demonstration tests, ABM was introduced as about 1% of the total feedstock of the kiln, and emissions monitoring was conducted to identify any fluctuations in the air emissions concentrations from the process. The final product was then subjected to physical and chemical analysis to determine the structural integrity of the product and whether the metals are bound in the crystalline structure of the cement. The results of these tests showed that the ABM in these proportions did not significantly increase the metals content of the clinker or lead to undesirable air emissions (Leonard et al., 1992).

The spent ABM at Mare Island Naval Shipyard is hazardous in the state of California and, if no recycling and/or reuse option were available, would have to be treated by stabilization/solidification and disposed of in a hazardous waste landfill. This technology makes beneficial reuse of the ABM by incorporating it into portland cement, where resulting metal concentrations are low and the metals are physically and chemically immobilized in the asphaltic concrete matrix.

Using ABM as a raw material in portland cement presents a cost savings for the waste generator and makes money for the operator of the cement kiln. In this Mare Island Naval Shipyard demonstration, the total fee charged by the kiln operator has been about \$195/ton for about 4,000 tons (3,600 metric tons) of recycled spent ABM. The kiln operator requires the fee to cover costs for the following activities associated with using the metal-contaminated ABM as raw material:

- transporting the spent ABM from the generator's site in northern California to the cement plant in southern California
- determining feedstock proportions and process modifications to accommodate the waste materials
- sampling and analyzing the clinker
- sampling and analyzing air emissions from the stack
- engaging in regulatory interaction to obtain necessary permits or variances.

The only significant cost element not included in the \$195/ton figure is the cost of ABM screening and debris disposal, which was borne by the shipyard and probably amounted to less than \$10/ton.

The unit cost for managing the Mare Island Naval Shipyard spent ABM as California hazardous waste was about \$660/ton. The waste management unit cost includes characterization, transport, and disposal in a hazardous waste landfill (including any treatment required by the landfill operator). Therefore, the cost savings to the generator are obvious and significant, and the kiln operator is being paid for a raw material that the cement plant usually has to pay for.

3.3.4.2 Using Solid Waste to Make Cement. Industrial Waste Management in St. Louis, Missouri reports the capability to use metals-contaminated waste as a raw materials substitute in cement making. Candidate raw materials are first analyzed to determine their suitability based on their value and contaminant level. The primary raw materials of interest are silica, calcium, aluminum, and iron. Good candidates for raw materials substitution typically contain 95% or more of these constituents. The company reports that its largest current source for substitute feed is fluidized-bed cracking catalyst.

Systech Resource Recovery Services in Xenia, Ohio accepts nonhazardous wastestreams containing low levels of transition metals as feedstock for cement kilns. Systech has a network of 16 cement kilns to process byproduct materials. Examples of acceptable feed materials include:

Alumina sources:

- catalysts
- ceramics and refractories
- coal ash
- adsorbents for gases and vapors

Calcium sources:

- lime sludges

Iron sources:

- coal slag
- foundry baghouse residuals
- iron mill scale

Silica sources:

- abrasives
- ceramics
- clay filters and sludges
- foundry sand
- sandblast media
- water filtration media

3.3.4.3 Using Spent Fluidized-Bed Cracking Catalyst to Make Cement. A company in Bucaramanga, Colombia has described preliminary testing of spent fluidized-bed catalyst as feed to a cement kiln. The catalyst contains about 60% silica (SiO_2), 33% alumina (Al_2O_3), 1% sodium, 2% iron, 0.03% copper, and 0.05% nickel. The catalyst is used as a replacement for clinker in the final grinding. Tests were performed with 30% and 40% catalyst replacing clinker. The resulting cement was reported to give compressive strength similar to the control cement sample. The catalyst cement set faster and required higher water-to-cement ratios to obtain workability. The authors noted that the high catalyst inputs were used to test the limits of possible additions. Input of catalyst to replace 30% of the clinker would use the annual production of catalyst in 1 week of cement making. Thus, in normal practice, lower quantities of catalyst would be used to produce a more conventional portland cement (Cardenosa et al., 1992).

3.4 Use Spent Abrasive as Concrete Aggregate

This section describes use of spent ABM and similar wastes as a portion of the aggregate in portland cement concrete. The value of ABM used as construction aggregate would be low. The average unit price for construction sand and gravel in 1993 was about \$3.60/ton (free on board [FOB] at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about \$6.75/ton to \$8.42/ton. The cost for construction sand and gravel ranges from about \$6.73/ton to \$9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995). The main economic advantage for this option is reduced disposal costs. Use of wastes in asphaltic concrete is described separately (see Section 3.5) due to the different characteristics required for the two different types of aggregate.

3.4.1 Description of Recycling Option

Aggregate is a mineral product from natural or manufactured sources used in concrete making. The specifications for fine and coarse aggregate are described in ASTM 33. The important features of aggregate are size grading; freedom from deleterious materials such as clay lumps, friable particles, and organic materials; and soundness.

The spent ABM could be used to form poured concrete surfaces or concrete blocks or shapes. The cement-making process is illustrated in Figure 3-4. Concrete blocks, bricks, and other shapes are made by combining and forming cement and aggregate. Concrete bricks typically are solid parallel-piped, whereas blocks have a central opening to reduce weight. A wide variety of specialty shapes also are made from cement and aggregate. Products in this category may be either nonreinforced or reinforced concrete products. Common examples of precast shapes include concrete barriers (New Jersey barriers); precast concrete septic tanks; precast concrete tanks, structures, and cribs; and precast concrete poles. Concrete made by substituting ABM for some of the fine aggregate would be more suitable for applications that do not require high strength such as riprap or fill for protective caissons around bridge pilings (Brabrand and Loehr, 1993).

This recycling technology is straightforward and involves little in the way of operation. Unless the reuse location is on site, the waste aggregate must be transported to the recycler's location. If the aggregate is going to be used as a construction material or as aggregate in concrete, it may be necessary to crush the waste and grade it by particle size. Storage requirements in compliance with any pertinent regulations may involve an impervious liner or bins or hoppers to prevent leaching. Special handling and worker protection also may be required to minimize exposure to dust.

3.4.2 Advantages of Recycling Option

The principal advantages to recycling spent ABM as aggregates are:

- using the spent ABM's favorable structural properties in a beneficial application
- conserving landfill space for the higher hazard waste materials
- reducing waste management cost.

Application of spent ABM as aggregate can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country, so long shipping distances can be avoided in many cases.

3.4.3 Limitations of Recycling Option

Use of spent ABM as a low-value component of a product that often is placed in direct contact with the land may be construed as "use constituting disposal" rather than as a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions or policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Use of the spent grit as aggregate chemically and physically immobilizes the contaminants. However, the effectiveness of solidification/stabilization is dependent on the integrity of the cement rather than on fundamental changes in the mineral form of the matrix and contaminant.

Rounded to subangular particle shape is preferred for portland cement concrete aggregate. Spent ABM typically would have more angular particles. Concrete containing a high proportion of spent ABM could have poor mixing, pouring, and setting characteristics (see the first example in Section 3.4.4).

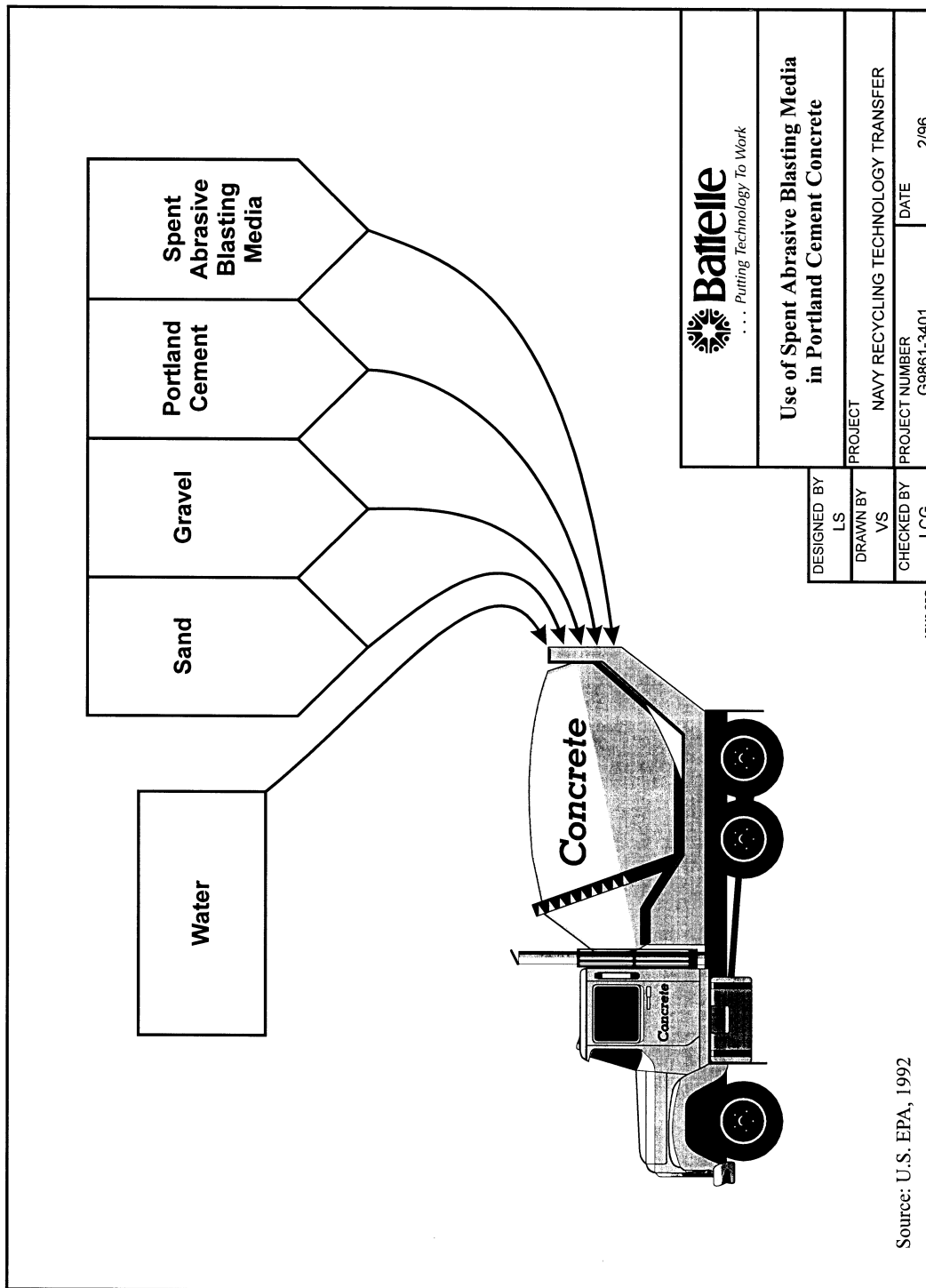


Figure 3-4. Use of Spent Abrasive Blasting Media in Portland Cement Concrete.

The alkali reactivity of the cement and aggregate is an important factor in selecting an aggregate. The concern is reaction of an alkali with the aggregate causing a volume increase and/or loss of concrete strength. The alkali causing the reaction usually is the calcium hydroxide released as cement cures. However, in some cases the alkali may come from external sources such as groundwater. There are two basic types of alkali-aggregate reactions:

- reaction of alkali with siliceous rocks or glasses
- reaction of alkali with dolomite in some carbonate rocks.

Some waste slags can exhibit excessive reactivity. For example, four zinc smelter slag samples tested by Oklahoma State University were found to be unsuitable as aggregate for portland cement due to the excessive expansion during curing caused by alkali aggregate reactions (U.S. EPA, 1990, EPA/530-SW-90-070C).

The alkali activity of a potential aggregate can be determined by one of several tests depending on the type of aggregate to be tested. The applicable tests or guides are ASTM C 227, "Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)"; C 289, "Potential Reactivity of Aggregates (Chemical Method)"; C 295, "Petrographic Examination of Aggregates for Concrete"; C 342, "Test Methods for Potential Volume Change of Cement-Aggregate Combinations"; and C 586, "Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)." Guidance for selecting the appropriate test method is given in C 33, "Standard Specification for Concrete Aggregates."

Waste aggregate used to produce mortar or other cementitious products should have a low metallic aluminum content. Aluminum metal is reactive in the cement paste and corrodes, releasing H₂ gas, causing expansion and decreasing the strength of the cement (Garner et al., 1993).

3.4.4 Example Applications

3.4.4.1 Using Spent ABM as Aggregate in Portland Cement Concrete. Literature was found describing three studies that used spent ABM as aggregate for concrete. The test materials and locations were (1) copper slag used for ship hull blasting in Baharain (Madany et al., 1991), (2) one coal slag and one copper slag used for bridge blasting in Pennsylvania (Weyand and Sutton, 1990), and (3) an unspecified sand from bridge blasting in Texas (Brabrand and Loehr, 1993).

Concentrations of leachable metals exceeded the TCLP limits in some of the unprocessed spent ABM. The Baharain study did not test TCLP leachability. Both the spent coal and copper slag ABM in the Pennsylvania study failed the lead TCLP. In the Texas study, two separate fractions of spent ABM (sand and dust) were collected by vacuum separation. The sand passed the TCLP test but the dust had leachable levels of lead, cadmium, and chromium.

None of the studies noted problems with leachable metals from the final product, but only the Texas study reported TCLP leachability results for the cement product. In the Texas study, metals leachability from both sand and dust materials was significantly reduced by small additions of cement. More cement would be needed to meet strength requirements than would be needed to immobilize the metals.

All of the studies concluded that spent ABM could be used to form low-strength concrete for nonstructural applications. However, in all cases the strength of the product was highly variable and much reduced when ABM was used to replace sand. As a general conclusion, spent ABM is marginally suited as a substitute for the sand portion of concrete aggregate.

3.4.4.2 Aggregate Production from Fly Ash Waste. In the Netherlands, fly ash is sintered to produce a material called Lytag that is suitable as a replacement for sand and gravel in aggregate. The sintering method has four process steps:

- mixing
- pelletizing
- sintering
- final processing

The mixing step combines water and fly ash to produce a paste. The carbon content of the fly ash must be 3% to 5% to provide fuel for the sintering process. If additional carbon is needed, it can be added in the mixing step. The damp powder is formed into pellets and moved by a conveyor to a hopper, which feeds pellets onto a belt in a layer 11.8 in (30 cm) thick and 6.6 ft (2 m) wide. The belt moves horizontally and passes under an ignition hood where, once inside, the upper surface layer of pellets is ignited. Air is drawn down through the pellets so that the combustion zone moves down through the material on the belt. The combustion process results in a temperature of 2,000°F (1,100°C) that causes the pellets to sinter. In the final production step, any pellets that have sintered together are separated by crushing and are screened to produce three size fractions: 0.02 to 0.16 in (0.5 to 4 mm), 0.16 to 0.32 in (4 to 8 mm), and 0.32 to 0.47 in (8 to 12 mm). Particles over 0.47 in (12 mm) are recrushed, and particles under 0.02 in (0.5 mm) are returned to the process.

The Lytag is reported to have a glassy surface due to sintering and, thus, to be leach resistant. The performance of Lytag as concrete aggregate is reported to be competitive with gravel. Lytag is being used in construction of two large bridges and various industrial and commercial construction projects in the Netherlands (Faase et al., 1991).

3.4.4.3 Aggregate Production from Incinerator Ash. A production process is being developed to remove ferrous and nonferrous metals from incinerator ash, processing the ash to prepare aggregate for concrete. The typical range of ash composition is:

SiO ₂	46 to 62%
Fe ₂ O ₃	7.6 to 17%
Al ₂ O ₃	5.5 to 10%
CaO	8.0 to 14%
Na ₂ O	3.6 to 7%
MgO	1.0 to 2%
SO ₃	0.4 to 2%

The ash passes through a series of crushers, screens, and magnetic separators to remove metals. The ash is first crushed with a jaw crusher and then passed through roll crushers. Ferrous metals are removed by magnetic separators. The roll crushers flatten the softer nonferrous metal particles into platelets. Ash leaving the roll crushers is screened with a 0.9-mm (0.035-inch) sieve. The metal platelets are retained while the mineral matter passes through the screen. The mineral residues are further crushed to pass through a 0.01-in (0.3-mm) sieve. The residues are blended with clay, pelletized, and fired in a rotary kiln to produce smooth spherical aggregate. The resulting aggregate has undergone testing in concrete for up to 4.5 years (Wainwright and Robery, 1991).

3.5 Use Spent Abrasive as Asphalt

This section describes the use of spent ABM and similar wastes as a portion of the aggregate in asphaltic concrete. The value of ABM used as construction aggregate would be low. The average unit price for construction sand and gravel in 1993 was about \$3.60/ton (FOB at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about \$6.75/ton to \$8.42/ton. The cost for construction sand and gravel ranges from about \$6.73/ton to \$9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995). The main economic advantage for this option is reduced disposal costs. Use of wastes in portland cement concrete is described separately (see Section 3.4) due to the different characteristics required for the two different types of aggregate.

3.5.1 Description of Recycling Option

The recycling of wastes into asphaltic concrete is not a particularly new concept. A wide variety of materials have been successfully substituted for some portion of the normal graded aggregate without adverse effects on product quality. The hot mix process for asphalt production is illustrated in Figure 3-5. The most widespread example of waste used as aggregate in asphaltic concrete is reuse of reclaimed asphaltic concrete from previous paving projects. Old asphalt paving is crushed and substituted for a portion of the aggregate in either cold mix or hot mix asphaltic concrete. More than 12,000,000 tons (10,900,000 metric tons) of asphalt were recycled by 35 asphalt contractors in 1992 (ARRA, 1994). The corresponding savings were over \$600 million in landfill costs and over \$30 million for liquid asphalt and aggregate. In certain situations, the old pavement is recycled into cold or hot mix asphalt in place, thereby reducing paving costs and reducing truck traffic on the highways to transport the old aggregate back to the contractor's facility (ARRA, 1994).

Another example of waste recycling into asphalt is the recently developed concept of using glass cullet as an aggregate in asphalt. The resulting product has been termed "glassphalt" (Monroe, 1990). Glassphalt uses mixed color glass which has low value in the conventional glass recycling market. Glassphalt containing 10% glass was used in a base course lift for the first time on a project in New Jersey. Highway agencies in Connecticut, District of Columbia, New Jersey, and Virginia have been using glassphalt on a trial basis (Ahmed, 1993).

The ABM-to-asphalt recycling technology involves simply substituting the ABM for a portion of the fine-size aggregate in asphaltic concrete. As long as the metal concentrations in the spent ABM are not excessively high, the metal concentrations in the asphaltic concrete product will be very low, and any metals present will be physically and chemically immobilized in the asphalt binder. Typically, asphaltic concrete consists of 4.5 to 8% bitumen mixed with graded aggregate. The aggregate is made by mixing rock and sand to give particles ranging from fine sand to 1/2- to 1-in (13-mm to 25-mm) gravel. Depending on the mix design and the ultimate strength requirements of the product, the fine-size particle fraction may comprise 35 to 45% of the asphaltic concrete.

3.5.2 Advantages of Recycling Option

Application of spent ABM as aggregate can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country so long shipping distances can be avoided in many cases.

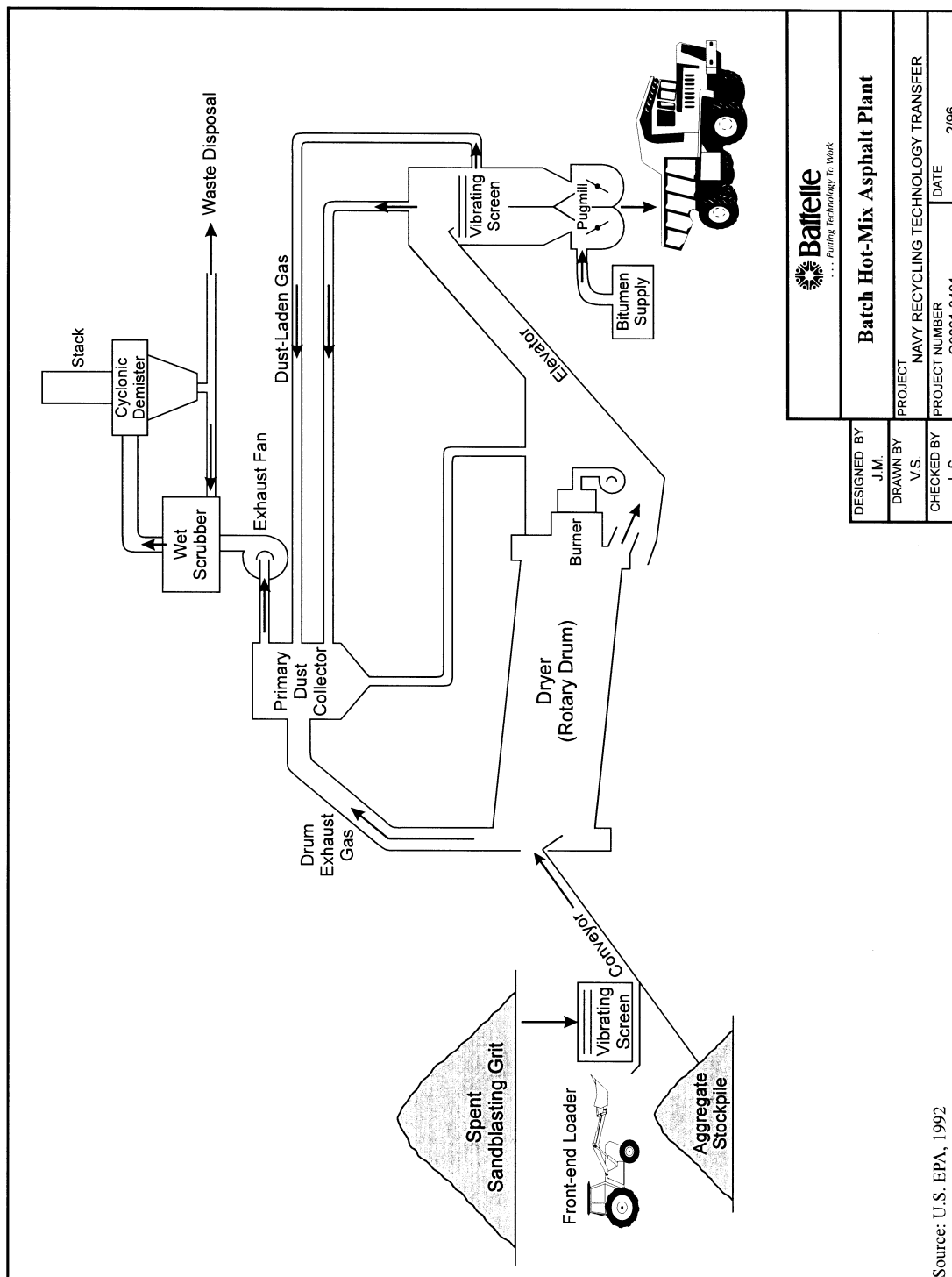


Figure 3-5. Illustration of the Hot-Mix Process for Asphalt Making.

 Battelle ... Putting Technology To Work		Batch Hot-Mix Asphalt Plant		
DESIGNED BY J.M.	PROJECT NAVY RECYCLING TECHNOLOGY TRANSFER			
DRAWN BY V.S.	PROJECT NUMBER G9861-3-401			
CHECKED BY L.S.	DATE 2/96			

Source: U.S. EPA, 1992

Applicable wastes include a wide variety of geologic materials, pavement, construction materials, ceramics, or glasses that are either aggregates or can be crushed to form aggregates. Because reuse usually is in the public domain, the wastes should contain only low levels of relatively low-hazard contaminants. The technology for reusing nonhazardous soil and sand wastes for asphalt aggregate is mature and commercially available. Oil-contaminated soil has been used as asphalt aggregate in construction projects for many years (U.S. EPA, 1992, EPA/600/R-92/096).

Sharp angular particle shape is preferred for asphaltic concrete aggregate. Spent ABM typically would have more angular particles and should provide a good substitute for the sand portion of asphalt aggregate.

3.5.3 Limitations of Recycling Option

The asphalt recycling approach is viable only for certain types of aggregates. The aggregate must comply with both performance and environmental standards such as durability, stability, chemical resistance, biological resistance, permeability, and leachability (Testa and Patton, 1994). The principal limitations pertain to risk, regulatory considerations, or technical considerations pertaining to the integrity of the asphaltic concrete product. For example:

- ABM containing solvents or other particularly hazardous or toxic constituents should not be recycled in this manner.
- ABM with high metal contents (percent level or greater) may pose hazards either to workers at the asphalt plant due to dust exposure or to the public through the asphalt product because of metals leaching.
- The presence of sulfate or metallic iron is undesirable because of swelling upon oxidation. Reduced forms of trace metals may cause similar problems, which, however, may be avoidable by recycling the ABM into a base course layer where there is minimal contact with air.
- High concentrations of silt and smaller size particles are undesirable because they have poor wetting characteristics in the bitumen matrix and may generate dusts.
- Rounded aggregates do not give good vehicle traction characteristics when used in asphaltic concrete.

The chief chemist or engineer at the asphalt plant must ensure that the ABM is compatible with the production of a high-integrity asphaltic concrete.

Use of spent ABM as a low-value component of a product that is placed in direct contact with the land may be construed as “use constituting disposal” rather than a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases, special wastes or state-regulated wastes may be recyclable, subject to state/local restrictions or policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Use of the spent grit as aggregate provides chemical and physical immobilization of contaminants. However, the effectiveness of solidification/stabilization is dependent on the integrity of the asphaltic concrete rather than on fundamental changes in the mineral form of the matrix and contaminant.

3.5.4 Example Applications

3.5.4.1 Using Spent ABM as Aggregate in Asphaltic Concrete. The NFESC in Port Hueneme, California has been studying the recycling of spent ABM in the form of sandblasting grit into asphaltic concrete for commercial paving purposes. The sandblasting grit is used as a “blender sand” for a portion of the fine-grained aggregate that is used to produce the asphaltic concrete. This section briefly describes the case history for the ongoing “ABM-to-asphalt” recycling project in Hunters Point, California.

The spent ABM at Hunters Point is comprised of a 4,000-yd³ (3,060-m³) pile of Monterrey Beach sand contaminated with small amounts of paint chips. The spent ABM was generated in ship-cleaning operations conducted at Naval Station, Treasure Island, Hunters Point Annex by Triple AAA Shipcleaning during the 1970s and 1980s. Average copper, zinc, lead, and chromium concentrations are 1,800, 1,100, 200, and 100 mg/kg, respectively. Leachable metals concentrations using the California Waste Extraction Test (WET) methodology average 140, 150, 20, and 2.0 mg/L, respectively for copper, zinc, lead, and chromium. The WET test is California's version of the RCRA TCLP. The spent ABM at Hunters Point is considered hazardous by the state because of Soluble Limit Threshold Concentration (STLC) exceedances on the WET test for copper and lead, but is not an RCRA-listed hazardous waste because it passes the TCLP.

In the ABM-to-asphalt technology demonstration at Hunters Point, an ABM concentration of 5% by weight of the final asphaltic concrete is being used so the spent ABM comprises 5% of the asphaltic concrete replacing about 1/9 to 1/7 of the normal sand portion of the concrete. Higher ABM contents are possible; theoretically the entire fine fraction of the mix design could be comprised of ABM. However, at higher ABM concentrations, there is greater potential for lower product quality or elevated leachable metals concentrations in the product.

At Hunters Point the ABM is being recycled into hot mix asphalt for normal commercial paving applications, yielding high-strength asphaltic concrete for heavily used highways. ABM can be recycled into both a base course layer or any subsequent lifts applied to the base course. ABM also can be recycled into cold mix processes, which yield a lower grade product for road repair or lower traffic area applications.

The cost of an ABM-to-asphalt recycling project will depend on a number of factors, particularly:

- tippage rate charged by the asphalt plant
- distance between the generator and the asphalt plant, which affects transportation costs
- required amount of planning, regulatory interactions, reporting, and program management

and to a lesser extent:

- analytical fees for chemical and physical analyses of asphalt test cores to show compliance with any regulatory or institutional requirements
- ABM pretreatment such as screening and debris disposal

In the Hunters Point project, the tippage rate charged by the asphalt plant is \$40/ton of ABM recycled. The overall unit cost about \$140/ton, including significant costs for transportation to the asphalt plant, regulatory compliance, and analytical testing of core specimens produced in the laboratory prior to full-scale recycling. In general, the recycling unit cost decreases with increasing amounts of spent ABM recycled. The following ranges are typical for most projects:

<u>Amount ABM (tons)</u>	<u>Estimated Costs of Recycling (per ton)</u>
500 - 1,500	\$125 - \$175
1,500 - 3,000	\$100 - \$150
3,000 - 6,000	\$ 50 - \$100

Therefore, economically, the ABM-to-asphalt recycling approach is a win-win situation for both the asphalt plant and the ABM generator. Recycling costs the generator less per ton than the cost for disposal in a hazardous waste landfill and probably less than it would cost for on-site treatment and disposal, and the asphalt plant is paid for a raw material that it ordinarily would have to buy.

3.5.4.2 Using Soil as Aggregate in Asphaltic Concrete. A review of the literature found two examples of application of metal-contaminated soils as asphalt aggregate. American Reclamation Corporation asphalt was used to stabilize soil contaminated with fuel oil and lead at a closed steel wire manufacturing plant. The contaminants reportedly were immobilized by the asphalt treatment, allowing the material to be used to pave the site after remediation was completed.

Applied Environmental Services treated soil from a railcar brake shoe manufacturing plant containing 438 mg/kg lead and 336 mg/kg zinc. The soil was excavated and treated off site at a cold mix asphalt plant. Treatment was reported to have achieved acceptable immobilization of the metals. The treated waste was returned to the site for use as paving (Testa and Patton, 1992).

3.5.4.3 Using Steel Shot as Aggregate in Asphaltic Concrete. The incorporation of steel shot ABM from bridge-blasting operations has been the subject of an ongoing demonstration project in North Carolina (Medford, 1989, 1990, and 1992). Recent results suggest that the steel shot ABM is not compatible with the asphaltic concrete product and is leading to premature failure due to the oxidation and swelling of the steel particles (Medford, 1992, personal communication).

3.5.4.4 Using Spent Foundry Sand as Aggregate in Asphaltic Concrete. Lead-contaminated foundry sands from brass foundries in Pennsylvania are being recycled into asphalt (Boyd, 1992).

3.6 Use Spent Abrasive as a Construction Material

This section describes using spent ABM or similar wastes as replacements for construction materials. Minimal preprocessing may be done to remove debris or reduce metal leachability. If the waste has high organic content, high leachable metal content, low strength, a high proportion of fines, or other undesirable properties, more aggressive processing may be needed to produce a usable product (see Section 3.7).

Crushed stone, sand, and gravel fill a wide range of needs in the construction, chemical feedstock, and other industries. The quantities used are enormous. For example, the estimated crushed stone production in the United States during the second quarter of 1995 was 367,500,000 tons (333,600,000 metric tons). The estimated production of construction sand and gravel in the United States during the second quarter of 1995 was 265,100,000 tons (240,700,000 metric tons) (Tepordei, 1995). The average unit price for construction sand and gravel in 1993 was about \$3.60/ton (FOB at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about \$6.75/ton to \$8.42/ton. The cost for construction sand and gravel ranges from about \$6.73/ton to \$9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995).

3.6.1 Description of Recycling Option

Sand and gravel are granular, unconsolidated agglomerations of rocks and minerals produced mainly by natural breakdown and abrasion of rocks (Bolen, 1993). The ASTM defines sand as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a Number 4-mesh U.S. standard sieve and are retained on a Number 200-mesh U.S. standard sieve. Gravel is defined as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a sieve with 3-in (7.62-cm)-square openings and are retained on a Number 4-mesh U.S. standard sieve. The construction industry generally accepts this differentiation of sand and gravel based on particle size.

Sand and gravel consist of a variety of rock and mineral types, so the composition varies. Silica is the major component of most commercial sand and gravel. Feldspar, mica, and iron oxides are common minor constituents. Specifications for sand and gravel used in roadbed and concrete construction usually state strict particle size gradation and shape requirements. Other requirements with regard to physical and chemical properties may be stated depending on the soil conditions, climate, and other locality-specific conditions. The National Aggregates Association has compiled 42 ASTM specifications and test methods for aggregates, concrete, and admixtures (Tepordei, 1993a).

The ASTM and the American Association of State Highway and Transportation Officials (AASHTO) are the main national organizations setting specifications on crushed stone for use in construction (Tepordei, 1993b). However, many specifications for construction aggregates are developed by states or localities based on their specific needs. Most common specifications control size grades, soundness, shape, abrasion resistance, porosity, chemical compatibility, and content of soft particles. Due to the skid resistance imparted to road surfaces when blast furnace or steel furnace slag is used as the aggregate, many state agencies specify slag aggregate for asphalt used for roads with high traffic volume (Solomon, 1993).

The American Railroad Engineering Association sets standards for railroad ballast. The general characteristics required of a good ballast material are strength, toughness, durability, stability, drainability, cleanability, workability, and resistance to deformation.

3.6.2 Advantages of Recycling Option

Application of spent ABM in general construction can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country so long shipping distances can be avoided in many cases.

When the physical and chemical characteristics allow the waste to be reused directly in a construction application, the processing is simple and uses commercially available equipment. Figure 3-6 illustrates one way of using spent ABM for contained fill. There is a well-established precedent for recycling waste materials with characteristics similar to spent ABM in the construction industry. In 1994, an estimated 19 million metric tons of iron and steel slags, with an approximate value of \$130,000,000, were recycled. About 80% of the recycled slags are used in construction applications such as road base, asphalt or cement aggregate, and fill. Other applications such as mineral wool manufacture, soil conditioning, and roofing account for the other 20% of slag use (Solomon, 1995b). Other ore-processing slags have been applied as drainage material in landfill construction and railroad road beds (U.S. EPA, 1990d, EPA/530-SW-90-070C). Spent foundry sand is another potential material for use in construction as road fill, aggregate, or daily landfill cover. About 6 million tons of spent foundry sand are produced annually by U.S. foundries, of which only 4.2% is put to beneficial reuse (Smith, 1992).

3.6.3 Limitations of Recycling Option

The principal requirements for the use of waste materials as aggregates or bulk materials are (1) acceptance by regulatory agencies, the customer, and the affected public; and (2) performance. Typically, the waste material must lend some useful function to the product and meet some leach-resistance criteria and specifications for physical properties (Wisconsin Department of Natural Resources, 1993). The end use should not be simply disposal in another form (termed “use constituting disposal” or “sham recycling”). Even if regulatory requirements and technical specifications are met, there may be reluctance on the part of the customer or the public to accept the use of those materials.

Wide use of waste materials for construction applications may pose the risk or perceived risk of exposing a large population to hazardous materials, generating occupational and public health concerns. The two principal exposure pathways are through inhalation of dusts or leaching of soluble metals from the aggregate into groundwater or surface water. Any recycling project using spent ABM in construction must have documented, quantitative evidence that no significant risk is being added to either the process or the product. Test results should demonstrate negligible incremental risk to the occupational workforce or to the public during processing of the material in its reuse environment. Potential liabilities may exist for the waste generator for real or perceived health effects resulting from the reuse.

The recycled material must equal or exceed the performance of the raw material it will replace. Product specifications for construction material include strength, size grading, chemical composition and purity, and chemical reactivity.

3.6.4 Example Applications

3.6.4.1 Using Ash in Construction Applications. Ash from a refuse-to-energy facility for processing of municipal waste is treated and used for landfill road construction. About 10 to 12% portland Type II cement is added to the ash. The treated ash is formed and cured to give a monolith which is crushed by equipment at the landfill. The resulting particulate is used as a subbase material for asphalt roadways at the landfill. The treated ash is accepted at no charge by the landfill and replaces recycled asphalt subbase that previously cost the landfill \$2/ton (Korn and Huitric, 1992).

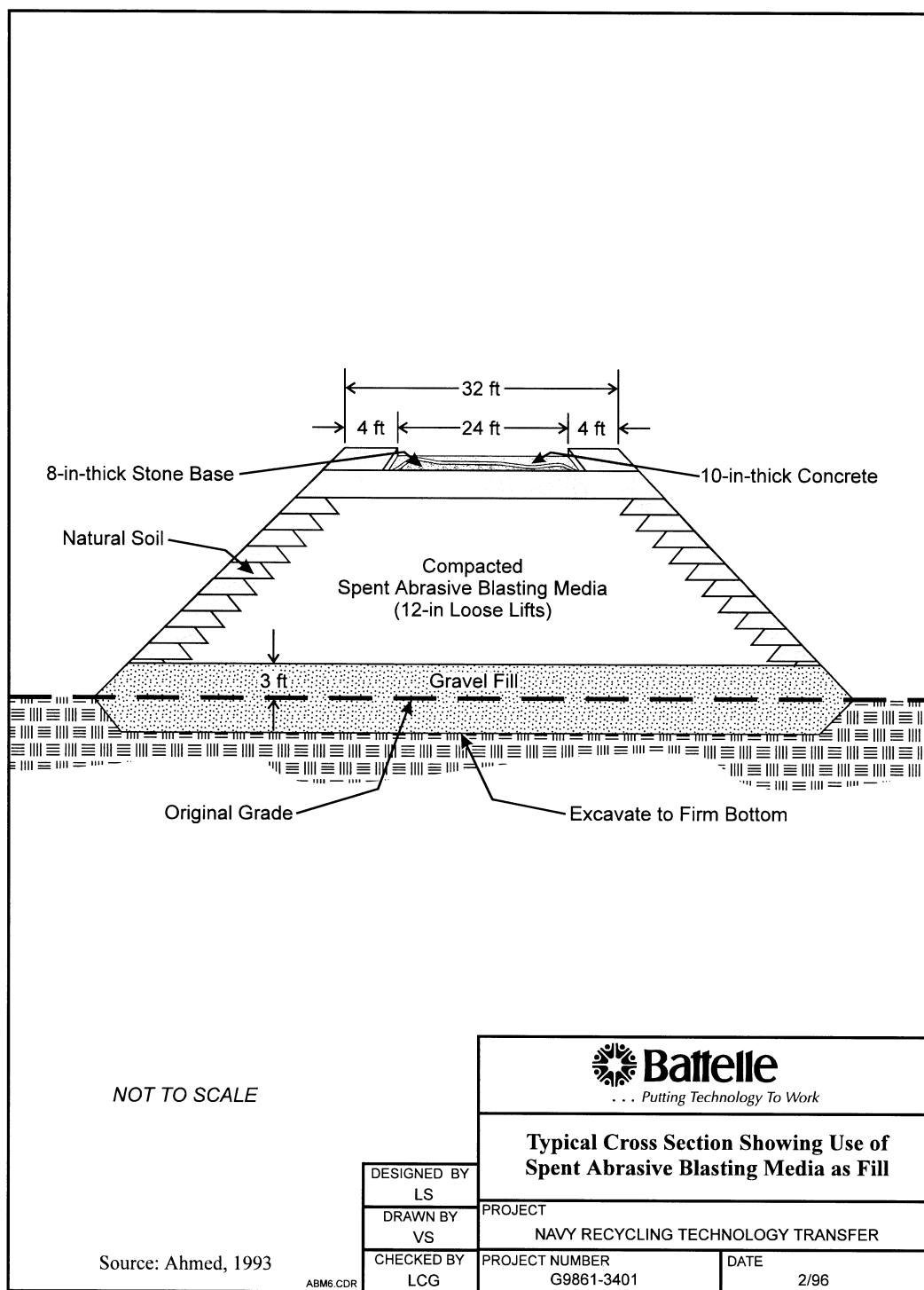


Figure 3-6. Typical Cross Section Showing Use of Spent Abrasive Blasting Media as Fill.

3.6.4.2 Beneficial Reuse of Foundry Sand. Foundry sand has been used extensively in construction applications. More complex sand and binder systems and increased concern over potential chemical hazards have resulted in a decline of such use in recent years. The Wisconsin Department of Natural Resources is developing a program to encourage responsible beneficial reuse of foundry byproducts. In particular, the state is developing fact sheets for beneficial reuse of foundry sand in applications such as these (Wisconsin DNR, 1993):

- foundation subgrade fill
- concrete and asphalt fine aggregate
- landfill daily cover
- pavement subbase fill
- contained embankment fill

3.6.4.3 Soil Recycling Demonstration. The Toronto Harbor Commissioner's soil recycling process produces reusable fill material by treating soils using a three-step process to remove organic and inorganic contaminants to produce a reusable fill material. First, soil washing reduces the volume of material to be treated by concentrating the contaminants in a fine slurry. The second step removes metals from the slurry by acidification and chelation. In the third step, chemical hydrolysis and biodegradation destroy organic contaminants concentrated in the slurry. The technology is reported to produce clean soil for reuse as fill material. A Superfund Innovative Technology Evaluation Program Demonstration took place in April and May of 1992 (U.S. Environmental Protection Agency, 1993, EPA/540/AR-93/517).

3.7 Vitriify Spent Abrasive to Form Construction Material

This section describes high-temperature processing to convert spent ABM or other wastes with a high silica content to low-value construction materials. Vitrification will destroy organic contaminants, reduce leachability of metals, and make a product with high compressive strength and a controlled particle size distribution. Thus, vitrification can be used to convert wastes with undesirable chemical and physical properties into a useful product. Thermal processing to produce high-value ceramic products is discussed in Section 3.2.

3.7.1 Description of Recycling Option

Waste vitrification is a thermal treatment technology that oxidizes, melts, and transforms a broad spectrum of wastes into a glasslike or rocklike material. The average composition of the earth's crust is compared to the composition of several glass formulations in Table 3-3. The similarity of the compositions indicates that mineral processing slags and minerals, such as those used to manufacture ABM, would be expected to be good candidates for vitrification.

Vitrification is accomplished by introducing the waste into a melting kiln or container where the waste is heated to form a liquid melt. A typical overall mass balance for vitrification using a plasma arc heat source in a reducing environment is shown in Figure 3-7.

The melting energy is derived from the oxidation of materials in the feed and from external heating of the waste material. Electrical conduction through the molten waste and plasma arc heating are two common methods for heat input. Some systems use fossil fuel heating, which reduces energy costs but increases the volume of off-gas generated.

Table 3-3. Comparison of the Earth's Crust to Common Commercial Glasses

Oxide Material	Average Composition of the Earth's Crust (wt%)	Typical Composition of Soda-Lime Glass (wt%)	Typical Composition of Borosilicate Glass (wt%)
SiO ₂	59.7	73.3	80.4
Al ₂ O ₃	15.5	1.5	2.3
Fe ₂ O ₃	7.2	0.1	0.0
CaO	5.1	9.8	0.0
Na ₂ O	3.8	14.2	3.8
MgO	3.5	0.3	0.0
K ₂ O	3.1	0.6	0.6
SO ₃	0.1	0.2	0.0
Cl	0.1	0.0	0.0
B ₂ O ₃	Trace	0.0	12.9

The discharged product usually provides high-volume reduction and a chemically durable material that typically passes the TCLP test as nonhazardous. The process typically collects particulates in the off-gas system and returns them to the melter feed to minimize secondary waste generation. For nonhazardous wastes, the discharged glass can be formed into useful construction materials, such as artificial aggregate, erosion-control boulders or slabs, or clean fill. Reuse of treated characteristic waste is possible (see Section 4.5.1 for a definition of hazardous characteristic). Testing will be required to demonstrate that the vitrification process removed the hazardous characteristic. However, it will be more difficult to identify markets of a material due to the previous waste code.

3.7.2 Advantages of Recycling Option

Vitrification of waste materials may be achieved over a broad range of earth and waste compositions and can immobilize many metal contaminants. The approximate solubility limit of a variety of common metal contaminants in glass is shown in Table 3-4 to indicate the general types and concentrations of metal contaminants that can be immobilized in a vitrified waste product. Examples of suitable wastes include sludge from wastewater treatment, electric arc furnace off-gas treatment residues, and baghouse dust (U.S. Air Force, 1990).

Vitrification has been adopted as the Best Demonstrated Available Technology (BDAT) for high-level radioactive wastes and for nonwastewater arsenic wastes. However, pretreatment usually is required to control arsenic volatilization during the vitrification process (U.S. EPA, 1990a, EPA/530/SW-90/059A).

The high-temperature vitrification process causes significant changes in the physical and chemical form of the matrix and the contaminants. Organic contaminants are oxidized to their mineral components. Metal contaminants are incorporated into a durable, leach-resistant mineral matrix. The discharged product is a chemically durable material that typically passes the TCLP test as nonhazardous. The process provides volume reduction (40% for soils to >99% for combustibles) (U.S. EPA, 1991, EPA/600/2-91/041).

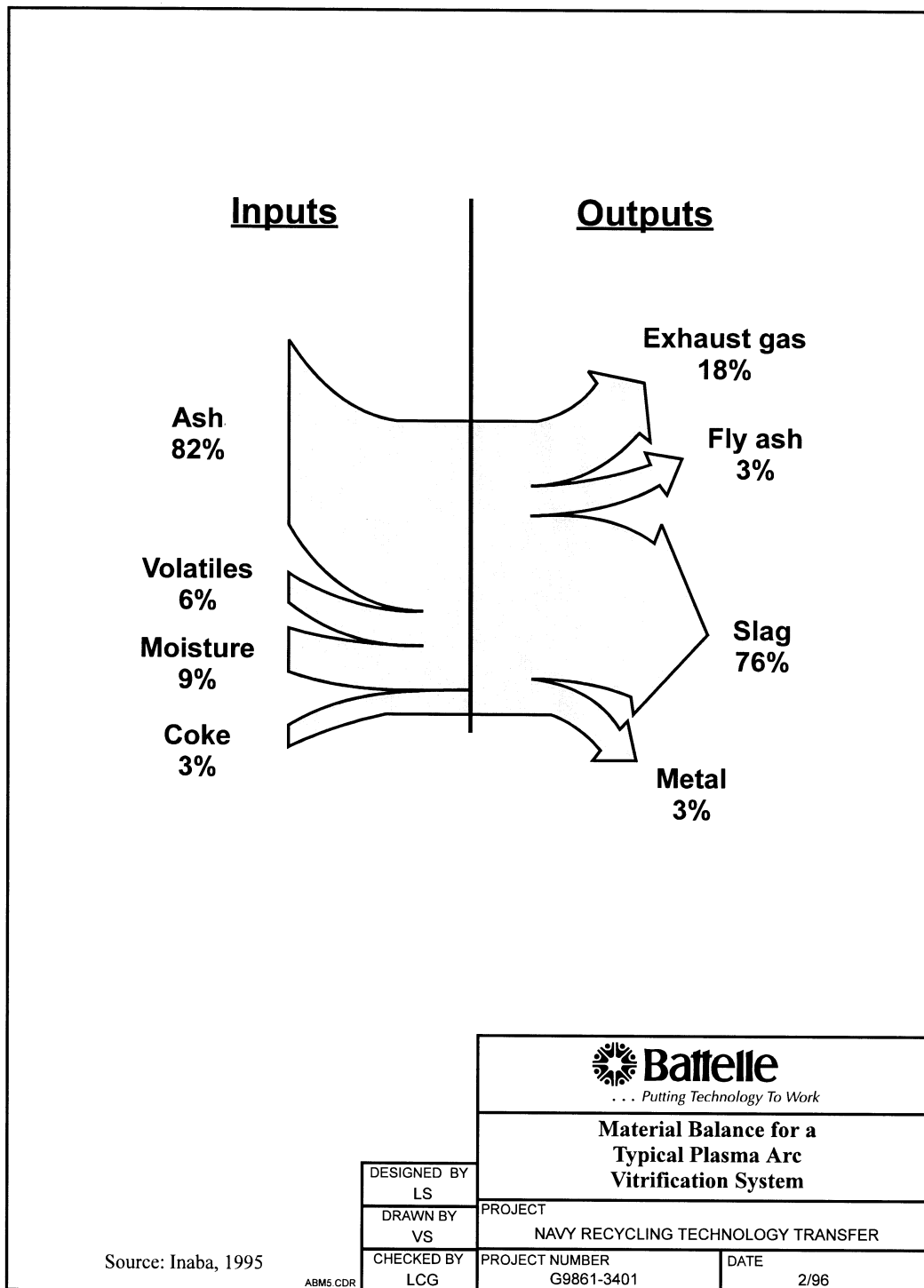


Figure 3-7. Material Balance for a Typical Plasma Arc Vitrification System.

Table 3-4. Approximate Solubility Limit of Oxides of Metals in Silicate Glass

Element	Maximum Allowed Oxide Content (%)	Element	Maximum Allowed Oxide Content (%)
Ag	0.1	Mg	30
As	5	Mn	10
B	20	Mo	2
Ba	15	Ni	5
Be	10	Pb	30
Cd	1	Sb	2
Co	2	Se	1
Cr	2	Sn	5
Cs	25	Sr	15
Cu	5	U	20
Ga	5	Y	1
Hg	0	Zn	20

3.7.3 Limitations of Recycling Option

The vitrification process is capital and energy intensive. Processing is unlikely to break even for wastestreams when forming a low-value construction material. The main economic advantage is avoided disposal costs.

The construction material made by vitrification of spent ABM often will be placed in direct contact with the land. Even though significant chemical and physical changes occur during vitrification, use of vitrified wastes may be construed as “use constituting disposal” rather than a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions/policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Volatile metals such as arsenic, mercury, or beryllium are difficult to treat and can be present only at low concentrations. Wastes containing arsenic will require some combination of pretreatment, special processing conditions, and off-gas treatment systems to minimize arsenic volatilization. If reducing conditions can occur in the melt, cadmium, lead, and zinc can vaporize and enter the off-gas stream (Hollander et al., 1995).

3.7.4 Example Applications

3.7.4.1 Vitrification of Nonhazardous Sludge. World EnviroTech in New York, New York designs, builds, and operates thermal treatment systems to convert nonhazardous wastes such as sewage sludge to aggregate. The primary processing chamber operates at 2,400°F (1,300°C). Waste material

reportedly is converted to an environmentally stable solid. The product can be either granulated (to a mainly vitreous form) or air-cooled (to a rocklike form) and is suitable for a wide range of uses as a replacement for sand and gravel. Example uses include preparing a subbase for roads, mixing in concrete as aggregate, or backfilling a pipe trench.

3.7.4.2 Waste Vitrification Process Options. Waste vitrification systems are under development or are available for hazardous and nonhazardous wastes from several vendors. Some examples of waste systems are summarized in Table 3-5.

Table 3-5. Examples of Some Waste Vitrification Process

Company/Process Name	Location	Process
Allis Mineral Systems/ Pyrokiln Encapsulation	20965 Crossroads Circle Waukesha, WI (414) 798-6265; fax (414) 798-6211	Fossil-fueled, direct-fired slagging rotary kiln ^(b)
Ausmelt	1331 17th Street, Suite M103 Denver, CO 80202 (303) 295-2216; fax (303) 295-7605	Fossil-fueled, direct-fired lance heater ^(c)
Babcock and Wilcox/ Cyclone Furnace	2200 Langhorne Drive Alliance, OH (216) 829-7394; fax (216) 829-7801	Fossil-fueled, direct-fired vortex furnace ^{(a)(b)}
Battelle/Terra-Vit	Battelle Boulevard, P.O. Box 999 Mail Stop P7-41 Richland, WA 99352 (509) 376-6576	Joule-heated melter ^(a)
Ecotechniek/Ecogrind	Het Kwadrant 1 Maarssen, 3606 The Netherlands (31-465) 577-00; fax (31-465) 544-72	Sintering in a rotary kiln ^(a)
EET Corporation/Microwaste Solidification Technology	129A Perimeter Park Road Knoxville, TN 37922 (615) 691-1223; fax (615) 691-2656	Microwave heating in drum ^(a)
Electro-Pyrolysis Inc./ Electro-Pyrolysis	996 Old Eagle School Road, Suite 1118 Wayne, PA 19087 (215) 687-9070; fax (215) 964-8570	Direct-current arc furnace ^(a)
EM&C Engineering Associates/ Vitriflux	1665 Scenic Avenue, Suite 104 Costa Mesa, CA 92626 (714) 957-6429; fax (714) 957-6414	Vitrification at low temperature using flux addition ^(a)
ENVITCO, Inc.	8400 West Central Avenue Sylvania, OH 43560 (419) 829-2728; fax (419) 537-1369	Small-batch, joule-heated melter ^(c)

Table 3-5. Examples of Some Waste Vitrification Process Vendors (Continued)

Company/Process Name	Location	Process
Ferro Corporation/ Waste Vitrifier	7500 East Pleasant Valley Road Independence, OH	Joule-heated melter ^(b)
Multiplex Environmental/ Xtaltite	4570 Westgrove Drive, Suite 255 Addison, TX 75248 (214) 733-3378; fax (214) 733-0366	Combination of hydrometal- lurgical and pyrometallurgi- cal processing to convert waste to a stable mineral form ^(a)
Penburthy Electromelt International, Inc.	631 South 96th Seattle, WA 98108 (206) 762-4244; fax (206) 763-9331	Joule-heated melter ^(c)
Plasma Technology Corporation/ Plasma Pyrolysis and Vitrification	8601 Six Forks Road, Suite 400 Raleigh, NC 27615 (919) 676-5304; fax (919) 676-5305	Plasma arc ^(c)
Retech/ Plasma Arc Centrifugal Treatment	100 Henry Station Road Ukiah, CA 95482 (707) 462-6522; fax (707) 462-4103	Plasma arc-heated rotating tub (centrifugal) melter ^{(a)(b)}
Stir-Melter/ STIR-MELTER Systems	Ampoint Industrial Park 995 Fourth Street Perrysburg, OH 43552 (419) 536-8828; fax (419) 536-8288	Joule-heated, stirred melter ^(a)
Vortec Corporation/ Combustion and Melting System	3770 Ridge Pike Collegeville, PA 19426 (610) 489-2255; fax (610) 489-3185	Fossil-fueled, direct-fired vortex furnace ^{(a)(b)}
Western Product Recovery Group, Inc./Coordinate Chemical Bonding and Adsorption	P.O. Box 79728 Houston, TX 77279 (713) 493-9321; fax (713) 493-9434	Sintering and partial slagging in a direct-fired rotary kiln ^(b)
Westinghouse Electric Corporation Science and Technology Center	1310 Beulah Road Pittsburgh, PA 15235 (412) 256-2235; fax (412) 256-1948	Plasma arc ^(c)

Sources:

(a) VISITT Version 4.0 (U.S. EPA, 1995, EPA/542-C-95/001).

(b) U.S. EPA, 1994, EPA/540/R-94/526.

(c) Vendor literature.

3.8 Processing in a Smelter

The metal content of spent ABM will not be sufficiently high to justify smelting to recover metals. The silica and calcium content may be useful as required slag-forming elements so that the spent ABM can be reused as flux in a pyrometallurgical process.

3.8.1 Description of Recycling Option

Pyrometallurgy is a broad term covering techniques for processing metal-bearing ores at elevated temperature. Processing at elevated temperature increases the rate of reaction and reduces the reactor volume per unit output. Elevated temperature often makes the reaction equilibrium more favorable. Pyrometallurgy, the oldest type of extractive metallurgy, dates back to the origins of recovering useful metals from ore. The earliest recorded use of pyrometallurgy was conversion of copper oxide ores to copper metal by heating with charcoal. This early type of pyrometallurgy was well established by 3,000 BC.

Pyrometallurgical processing to convert metal compounds to elemental metal usually requires a reducing agent, fluxing agents to facilitate melting and to slag off impurities, and a heat source. Figure 3-8 shows examples of oxidation and reduction smelting. The fluxing agents form a eutectic or other low-melting-point material due to the chemistry of the melt. An acceptable melting point is achieved by adding fluxing agents such as calcium oxide or by appropriate blending of the feedstocks. The most common fluxing agents in mineral smelting are silica and limestone. The spent ABM could be used to replace mineral raw materials as a source of silica. The spent ABM may contain trace metals that are recovered by the smelter, but the quantities would be incidental. The main recycling benefit from the ABM would be to provide silica.

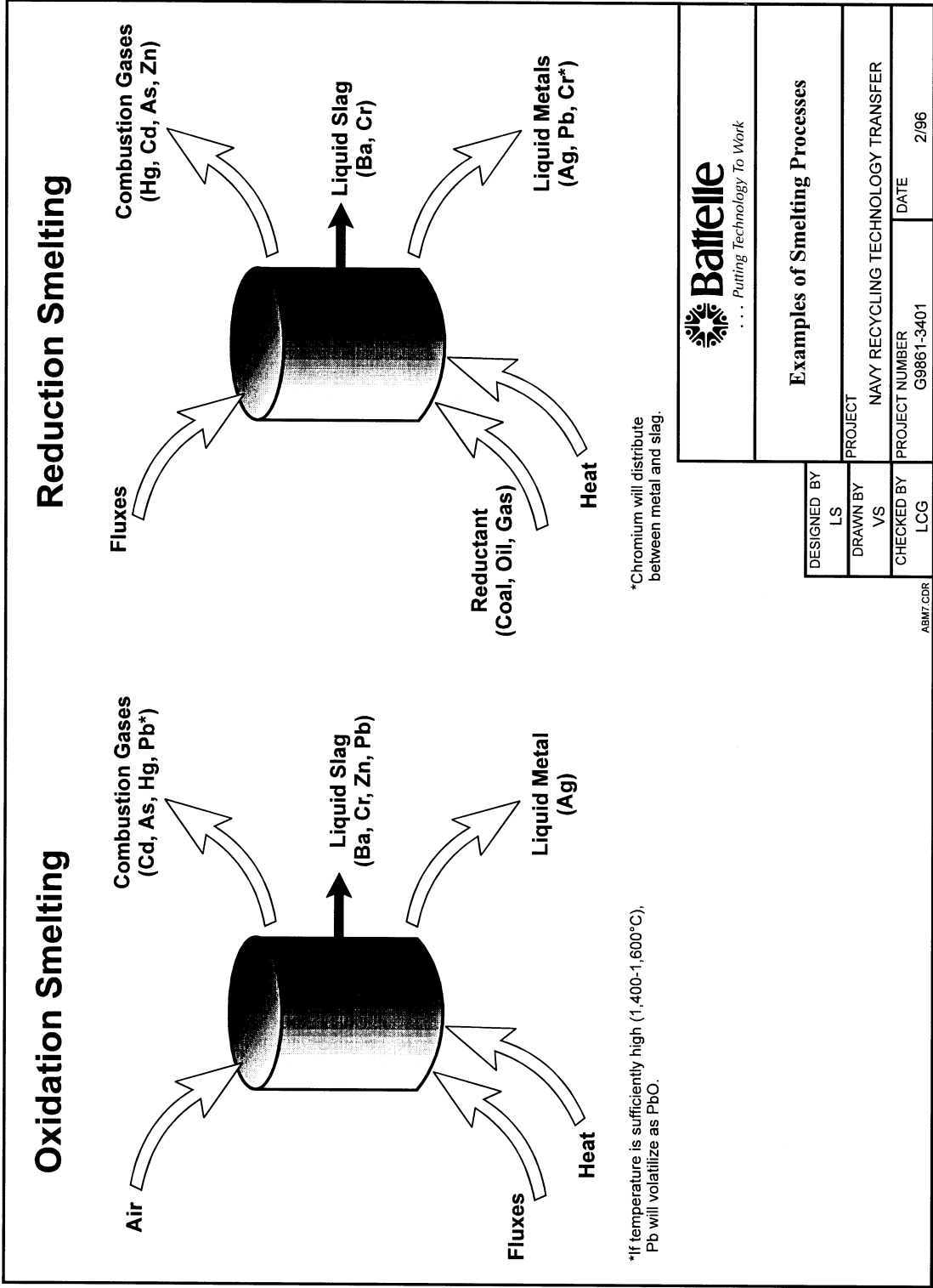
Separating the metal from the undesirable waste components typically is accomplished by physical action based on phase separations. As the metal salts react with the reducing agent to form metal or matte, the nonmetallic portions of the ore combine with the flux to form a slag. Volatile metals such as zinc and cadmium vaporize and are collected by condensation or oxidation from the off-gas, usually as oxides due to combustion of metal fume in the flue. Dense, nonvolatile metals can be separated from the less dense silicate slag by gravity-draining the metallics from the bottom of the reaction vessel. Slag oxides are tapped from a more elevated taphole.

3.8.2 Advantages of Recycling Option

Using spent ABM or other high-silica wastes in a smelter offsets the consumption of rock while producing a leach-resistant slag. The slag is similar to the product made by vitrification (see Sections 3.2 and 3.7). Using the waste in a smelter takes advantage of existing equipment to avoid the high capital and operating cost of a vitrification unit.

3.8.3 Limitation of Recycling Option

The slag chemistry in a smelting furnace must be closely controlled to produce a low-melting mix that scavenges impurities and helps to chemically reduce metal salts in the ore to elemental metal. Silicon and calcium compounds are desirable in helping to form a slag with the correct melting point. High-melting oxides such as alumina are undesirable. The smelter operators will be required to frequently sample and analyze the wastes to ensure they are compatible with the slag chemistry.



3.8.4 Example Applications

3.8.4.1 Using Ash in Copper Smelting. Cyprus Miami Mining in Claypool, Arizona is a primary copper smelter used to process complex sulfide ores (LaChappelle and Dyas, 1993). The smelter produces copper as its main product with a small, but valuable, byproduct stream of gold and silver. Volatile metals such as lead, arsenic, and mercury are captured by acid scrubbing and sent to other facilities for recovery. The company is reported to be an exempt recycling facility with the capability of accepting D002 through D011 characteristic waste and F006 listed waste. The facility accepts selected metals; metal sludges or filter cakes; and incinerated ashes containing copper, silver, or gold. Processing ash from incineration of municipal wastewater treatment sludge provides silica as a flux and allows recovery of the trace quantities of gold and silver in the sludge. The plant also processes used foundry sand and lime residues from boiler cleaning. These materials provide fluxing agents and allow metal recovery.

3.8.4.2 Smelting Lead-Containing Wastes. The Center for Hazardous Materials Research and Exide/General Battery Corporation are demonstrating the use of secondary lead smelting to reclaim usable lead from waste materials containing between 1 and 50% lead. The characteristics of secondary lead smelters in the United States are summarized in Table 3-6. Waste containing 1 to 25% lead is treated in a reverberatory furnace to produce slag containing about 70% lead. The slag and other high-lead-content materials are fed to a blast furnace to produce lead metal products. Testing as part of the Superfund Innovative Technology Evaluation (SITE) Program has been performed on a variety of waste materials including battery cases, slags, lead dross, and lead paint chips. Materials from Superfund or other contaminated sites could be mixed with other higher grade lead material for smelting. The reported treatment cost ranges from \$150/ton to \$250/ton for Superfund materials (Timm and Elliott, 1993). The process has been used to treat about 1,350 tons (1,225 metric tons) of lead-bearing materials from the NL Industries Superfund site.

Table 3-6. United States Secondary Lead Smelters (November 1993) (Source: Smith et al., 1995)

Smelter Location	Year Built	Approximate Capacity MTPY ^(a)	Furnace Type ^(b)
Ponchatoula, LA	1987	8,000	BF-SRF
Boss, MO	1991	65,000	REV (Paste) SRF (Metal)
Lyon Station, PA	1964	54,000	REV-BF
Muncie, IN	1989	70,000	REV-BF
Reading, PA	1972	65,000	REV-BF
College Grove, TN	1953	10,000	BF
Eagan, MN	1948	55,000	REV-BF
Tampa, FL	1952	18,000	BF
Columbus, GA	1964	22,000	BF
Frisco, TX	1978	55,000	REV-BF
Los Angeles, CA	1981	90,000	REV-BF
Rossville, TN	1979	9,000	BF
City of Industry, CA	1950	110,000	REV
Indianapolis, IN	1972	110,000	REV-BF
Wallkill, NY	1972	70,000	REV
Troy, AL	1969	110,000	REV
Baton Rouge, LA	1960	70,000	REV-BF
Forest City, MO	1978	27,000	BF
Total secondary lead smelting capacity		1,023,000	

(a) As lead metal.

(b) BF = blast furnace; REV = reverberatory furnace; SRF = short rotary kiln.

4.0 EVALUATING RECYCLING OPTIONS FOR SPENT ABRASIVE

This section describes factors to consider when evaluating reuse and recycling options for spent ABM and other similar wastes.

4.1 Contaminant Characteristics

The types of contaminant present, their concentration, and their physical and chemical forms are major considerations in selection of a reuse or recycling option. Questions should be asked about the critical features of waste composition:

- Is the spent ABM suitable for cleaning and reuse?
- Will a mixture of metals in the waste complicate recycling?
- Will inorganic salts in the waste complicate recycling?
- Will organics in the waste complicate recycling?

The contaminant composition is determined by chemical and mineralogical analysis on a representative group of samples. The analysis should go beyond determining the concentration of the contaminants. The chemical form and speciation are important factors when considering recycling options. Matrix properties also are important (see Section 4.2).

Some fraction of the spent ABM will have the required particle size and shape to allow reuse for blasting if the impurities can be removed. Physical separation, thermal processing, or a combination of the two methods may be used to recover and restore the usable portion of the spent material.

A waste containing a limited number of contaminants generally is easier to recycle. Wastes containing a single type of metal contaminant are more likely to be suitable for higher-value uses. Segregating hazardous from nonhazardous wastes can be particularly helpful. Finding recycling options will be more difficult if the waste has a RCRA hazardous waste designation. It is often beneficial to separate spent ABM to be used for cleaning newer ships from spent ABM to be used for cleaning older ships. In 1977, the Consumer Product Safety Commission banned the use of lead-containing paints for residential use. Although there is no specific regulation banning the use of lead-containing paints for industrial coatings, lead primers have been nearly eliminated from use since the early 1980s (Leighton, 1995). Older coating materials containing lead can cause the spent ABM to be a RCRA-listed hazardous waste. If all spent ABM wastes were mixed, the volume of hazardous waste could be increased and recycling options decreased. However, plans for waste segregation should consider the desire of end users for a reliable supply of homogeneous material and the added cost of sampling and analyzing many different waste groupings (see Section 4.4.2).

Antifouling additives are a unique feature of marine coatings. The compounds used in antifouling paints for ships can introduce metal contaminants to the spent ABM. These antifouling paints serve a pest control function and must, therefore, be registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Copper-based antifouling coatings traditionally were favored but were largely replaced by organotin formulations that gave more reliable protection. Use of organotin antifouling coatings has been restricted worldwide, and the FIFRA registration of organotin coatings is under review by the U.S. EPA. With the increased regulatory scrutiny, the popularity of organotin antifouling coatings has been declining (Holder and Montemarano, 1995).

Inorganic salts can interfere with specific recycling options. For example, chlorides increase the volume of kiln dust waste from cement manufacturing and chlorides or sulfates produce acidic off-gas from thermal processes.

The presence of high concentrations of organic contaminants can complicate the recycling of spent ABM, but petroleum contaminants can be acceptable with some recycling options. Organic contaminants with properties similar to bitumen (e.g., the higher-molecular-weight hydrocarbons) are compatible with asphalt. Therefore, petroleum hydrocarbons may be tolerated, if the spent ABM is to be used for asphalt. Vittrification and cement-making require energy input; therefore, the waste can contain an organic contaminant if it burns to provide energy and does not add impurities or produce unacceptable off-gas.

4.2 Waste Characteristics

The waste matrix properties will affect the acceptability of the waste material for various recycling methods. For construction applications, the material matrix is the recycled product. The waste matrix affects the compatibility of the waste matrix with the intended end use. Review of waste matrix effects is aimed at answering these types of questions:

- Is the waste matrix compatible with the existing recycling processing techniques and equipment?
- Will the waste matrix increase or decrease contaminant mobility?
- Does the matrix have value as a bulk commodity?

The potential user of a recyclable waste will prefer a material with physical and chemical properties similar to those of the conventional raw material. In general, there will be a preference for a dry granular solid with a uniform concentration. The highest possible and most permanent leaching resistance is desirable and, of course, all regulatory leaching resistance requirements must be met.

Any recycling option will require simple pretreatment of the waste to upgrade, blend, or otherwise develop more uniform or desirable characteristics for the end user. At a minimum, the waste should be passed through a large mesh screen to remove trash and oversize material. Additional physical separations processing may also be useful. For example, crushing to reduce the size of large clumps followed by screening to remove both oversize debris and undersize dust will produce a more uniform particle-size material and may increase the value or range of applicable recycling options.

More complex separation processes are available to upgrade the spent ABM. Magnetic separation can remove ferromagnetic metals. Beneficiation processes involving water-assisted physical separation such as jigging, hydrocyclone separation, or tabling separate particles based on size, shape, and density. However, the added cost of the more complex beneficiation methods is more difficult to justify when dealing with wastes that are suitable only for lower-value uses.

It is important to note that conventional materials are not totally free of trace metal impurities. The metal content of the spent ABM may be within the range of composition of the conventional material it replaces. The trace element content of soils is shown in Table 4-1 to provide a general basis for comparison.

4.3 Site Characteristics

Site characteristics such as infrastructure capabilities and support service supplies may either favor or interfere with removal or handling of the waste material. Examination of site characteristics is directed at answering these types of questions:

Table 4-1. Trace Element Content of Soils

Element	Common Range in Soil (mg/kg)	Average Concentration in Soil (mg/kg)
Ag	0.01 to 5	0.05
As	1 to 50	5
B	2 to 100	10
Ba	100 to 3,000	430
Be	0.1 to 40	6
Cd	0.01 to 0.7	0.06
Co	1 to 40	8
Cr	1 to 1,000	100
Cs	0.3 to 25	6
Cu	2 to 100	30
Ga	0.4 to 300	30
Hg	0.01 to 0.3	0.03
Mg	600 to 6,000	5,000
Mn	20 to 3,000	600
Mo	0.2 to 5	2
Ni	5 to 500	40
Pb	2 to 200	10
Sb	2 to 10	No data
Se	0.1 to 2	0.3
Sn	2 to 200	10
Sr	50 to 1,000	200
U	0.9 to 9	1
Y	25 to 250	50
Zn	10 to 300	50

Source: U.S. Environmental Protection Agency, 1983, SW-874.

- Is the material accessible for removal?
- Can the contaminated solid be moved efficiently by conventional bulk material handling equipment and techniques?
- Will the on-site and off-site infrastructure support transport of the waste materials?
- Are the required utility supplies and support services available?

Removal logistics are determined by access to the contaminated site for excavation, the ability to handle excavated material, space for placement of aboveground treatment equipment, and the road and rail system on and around the site. Recycling usually requires development of storage areas to allow for pretreatment of the waste (see Section 4.2), to accumulate sufficient volumes of uniform feed to satisfy user needs, and to stockpile material between projects. The surge storage will increase space requirements and may increase regulatory concerns.

Data needed to evaluate the removal logistics include maps of the site and surroundings. Important features to consider include the general arrangement of structures and infrastructure and the location of critical environments or sensitive receptors.

4.4 Economic Factors

Economic factors including costs, market conditions, and time available for remediation play a major role in the identification and selection of recycling options.

4.4.1 Operating and Capital Costs

A reuse or recycling option is evaluated as a competitor among a group of options. To be acceptable, an option must effectively protect human health and the environment. In most cases, once effective options are identified, the one with the lowest implementation cost is selected. The economic analysis will need to consider the capital investment required to implement the candidate options and the overall cost of the recycling versus treatment and disposal. Questions typically considered as part of the economic evaluation include:

- Is there a profitable recycling option?
- Will consideration of life-cycle cost factors improve the competitive position of recycling?
- Do intangible factors favor recycling?
- Does recycling require a major investment of capital?

The value or cost of recycling spent ABM will be determined by competition with other raw materials in the marketplace. If a paying recycling market is identified for the spent ABM, treatment and disposal options should not be considered.

There usually will be a fee associated with recycling options for spent ABM and similar wastes. Recycling options will then need to be evaluated in competition with treatment and disposal alternatives, except where treatment and disposal are precluded by land ban requirements (e.g., wastes containing high concentrations of mercury or emission control dust or sludge from electric arc furnaces K061).

The economic analysis should include both direct costs and avoided expenses through the life cycle of the alternative considered. Intangible factors such as improved public image or the potential for liability should be considered. It may be appropriate to include some correction for costs that may occur but that cannot be quantified. For example, disposal options may result in liability for cleanup at a future date.

The relative capital costs can also influence a decision. Even if one option has a lower life-cycle cost, a higher total cost option with lower capital cost may be chosen due to limited availability of capital.

4.4.2 Recycling Market

The recycled spent ABM must compete effectively with conventional products filling the same needs. The competitive position of the contaminated material should be considered to address questions such as these:

- Will the recycled product equal or exceed the performance of competing products already in the market?
- Are adequate markets available within a reasonable shipping distance?
- Will the volume of material available for recycle justify the effort required to do the recycling?

Products formed from waste materials must meet or exceed the performance specifications of existing products. For example, ASTM C 825, "Specification for Precast Concrete Barrier," describes the required characteristics of formed concrete products given in the specification for New Jersey barriers.

The barrier specification combines requirements on materials, design, manufacture, and physical performance. The materials used (cement, aggregates, air-entrainment additives, and steel reinforcement) must meet applicable ASTM specifications. The design factors specified are concrete strength and air content, dimensions, reinforcement placement, finish, lifting devices, and anchorage points. Requirements for the manufacturing steps of mixing, curing, and forming are given. Test methods and required performance are given for compressive strength and dimensional tolerance.

The form of the barrier specification illustrates one hurdle for waste-derived products. For many waste-derived products, the materials and method of manufacture are totally different from those used in making the existing product. The customer may be unwilling to accept the new manufacturing methods even when the measured physical and chemical properties are equal or superior. The customer is concerned that the quality of the product is affected in part by features or interactions too complex to be measured by physical properties alone, so the quality of the raw materials and the production process must be specified and controlled. As a result, a waste-derived product often must undergo a lengthy demonstration to prove performance in real-world applications.

The location of the site and the volume of spent ABM can influence the economic viability of recycling. The shipping, handling, and storage costs can be a significant portion of the total cost, particularly with low-unit-value aggregate or construction materials. A waste source located near the end user will reduce shipping costs.

Industrial users prefer a steady supply of consistent materials. The desire for a homogeneous feedstock often is not consistent with the realities of waste production. Both the matrix composition and the contaminant levels in wastestreams can be highly variable. Also, as discussed in Section 4.1, waste segregation can help reduce the volume of hazardous wastes produced but will increase the number of waste types. Waste segregation efforts must consider a tradeoff between reducing the volume of hazardous wastes versus the increased complexity introduced by having many waste types. When wastes are segregated in small batches, each batch must be characterized, increasing sampling and analysis costs and increasing the challenges in marketing several smaller volumes of wastes.

Preprocessing the waste to improve homogeneity is a possible approach to improving market acceptance. However, additional processing increases the cost to implement the option and the complexity of the equipment needed on site.

4.4.3 Time Available for Remediation

Evaluation of reuse and recycling options should consider the amount of time required to mobilize, operate, and demobilize the selected option in relation to the time actually available to perform the work. Consideration of the timing of the options is directed at answering these types of questions:

- Can the cleanup be completed in a time frame consistent with health, safety, and environmental protection?
- Can the cleanup be completed in a time frame consistent with the end use requirements?

The time available for remediation is controlled primarily by the need to protect human safety and health and the environment. If a toxic contaminant is present, the contaminant concentration is high, or the contaminant is mobile and near a critical ecosystem, the remediation must proceed quickly. Time

available may be controlled by the value or intended end use for the site. It is undesirable to keep a high-value site out of productive use for a long period.

Identification of recycling options, definition of applicable specifications, testing to determine their suitability, and negotiating contracts to do the recycling can require more time than conventional treatment technology. If the contaminant presents an imminent danger due to hazard level, mobility, or other factors, rapid remediation is needed. The need for rapid remediation of an imminent hazard favors treatment.

The importance of the length of remediation time may be lessened if the time constraint is driven by economic or end use requirements. Depending on the site logistics and the site use, it may be possible to continue routine site operations while material is removed (and, if appropriate, while it is processed on site) for recycling. However, the need for rapid remediation still generally increases the favorability of treatment technologies.

4.5 Regulatory Considerations

Regulatory constraints describe the overall regulatory climate at the site based on federal, state, and local regulations. Typically the recycled material fills only a small portion of the user's feed material requirements. Should the regulatory requirements or liability concerns be large, the user typically has a competitive source of virgin material to replace the recycled material. As a result, regulatory issues can present a significant challenge to recycling of materials with a RCRA waste code or coming from a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. Examination of regulatory standards is directed at answering such questions as these:

- What contaminant control levels are required?
- Are the materials controlled by RCRA hazardous characteristics or listings?
- Are the materials controlled by state or local hazardous or industrial waste regulations?
- Can a valid reuse, reclamation, or recycling process be applied to exempt RCRA waste?

Regulatory considerations often are the most important factors influencing the viability of a particular recycling option. Therefore, before plans for recycling are pursued in depth, it is important to determine the federal, state, and local regulations that may be applied to a particular site, waste material, and/or recycling option.

Regulations pertaining to recycling vary widely from state to state; in addition, the prevailing attitude on the part of the regulator towards recycling will vary based on a number of factors, such as prior track record, perceived risk, and other factors. It is not possible here to define or predict the compliance issues that may be encountered on a project-by-project basis. The remainder of this section summarizes U.S. EPA and some examples of state regulations that pertain to the recycling of spent ABM. The discussion of state regulations and policy pertains primarily to California, Oregon, and Washington but may provide some generic perspective on the types of compliance issues that may be encountered in other states as well.

4.5.1 Federal Regulations — RCRA

One of the first steps in identifying the regulatory requirements is to determine if the spent ABM is considered a hazardous waste under RCRA. This law and the regulations issued pursuant to the law place stringent requirements on the storage, treatment, and disposal of hazardous waste. Under RCRA, a waste may be considered hazardous if it is either specifically listed (e.g., certain spent solvents from certain processes or specific chemicals) or it may be hazardous by characteristic (i.e., it is ignitable, reactive, corrosive, or “toxic” based on the TCLP). For spent ABM, it is most often the metals from the paints (e.g., lead) that cause the waste to fail the TCLP and thus be considered a RCRA hazardous waste.

Because of extensive regulatory tracking, reporting, testing, and in some cases, permitting requirements, and because of concerns for future liability, many companies are not willing to accept RCRA hazardous wastes as substitutes for their normal raw materials. Therefore, it is important to know if the waste is RCRA hazardous and to discuss any proposed reuse/recycling with the potential recycler before proceeding. In addition, the U.S. EPA or their delegated regulatory agency has authority over recycling of RCRA hazardous wastes and it is critical to determine whether the recycling option will be allowed by the regulatory agency before engaging in the process.

The regulation of recycling RCRA hazardous waste is a complex and evolving area. The U.S. EPA is considering revising the existing regulations to make legitimate recycling easier; however, these revisions are not yet in place. The regulation of recycling is still quite complex and is often determined on a case-by-case basis. An overview of the existing recycling regulations and policies is discussed below.

Rules issued by U.S. EPA on January 4, 1985 (50 FR 614) acknowledged the need to encourage safe recycling of hazardous wastes — particularly when recycling clearly reduces potential harm — while at the same time assuring the abatement of pollution and the prevention of harm to human health and the environment.

For a secondary material to be regulated under RCRA Subtitle C, a substance must first meet the definition of a “solid waste.” Section 1004(27) of RCRA defines solid waste as:

any garbage, refuse, sludge, ... and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities.

A central element of this definition is that wastes are “discarded.” In 1985, the U.S. EPA revised the definition of solid waste to further clarify when a secondary material that will be recycled is considered a solid waste. Under the regulatory definition of solid waste, found in 40 CFR 261.2(a-f), a secondary material is defined as a solid waste if:

- it is abandoned
- it is recycled in certain ways, or
- it has been defined as “inherently waste like.”

The term “secondary material” refers to spent materials, sludges, byproducts, commercial chemical products, and scrap metals. “Spent material” is defined as a material that has been used, which as a result of contamination can no longer serve the purpose for which it was produced without further processing. When any of the five types of secondary materials are “recycled in certain ways,” they may or may not be defined as solid wastes. The U.S. EPA has made distinctions between recycling that is

regulated as waste management and recycling that is exempt from regulation, depending on the type of secondary material and the manner in which it is being managed.

With respect to the second item, “recycled in certain ways,” secondary materials are solid wastes, and thus are subject to regulation, when they are recycled in the following four ways:

- used in a manner constituting disposal (i.e., applied to the land or used to produce a product that is placed on the land) [note that use of hazardous waste in asphalt and concrete generally is considered use constituting disposal.]
- burned for energy recovery (including use to produce a fuel)
- reclaimed (processed to recover a usable product or component or regenerated), or
- accumulated speculatively (material stored with less than 75% recycled within 1 calendar year).

The regulations state that when any of the secondary materials identified above is recycled in any of the four ways indicated, it is defined as a solid waste, with four primary exceptions:

- characteristic sludges being reclaimed
- characteristic byproducts being reclaimed
- commercial chemical products being reclaimed, or
- commercial chemical products being speculatively accumulated.

Characteristic sludges and byproducts used in any of the remaining three ways (i.e., placed on the land, burned for energy recovery, or accumulated too long before recycling) are solid wastes. Commercial chemical products that are placed on the land or burned for energy recovery also are solid wastes, unless that is their ordinary use.

In addition to the exclusions discussed above, the U.S. EPA recognized other situations that closely resemble production processes and, therefore, are excluded from regulation under the RCRA program. Materials are not solid wastes when they are legitimately recycled by being:

- used or reused as an ingredient in an industrial process to make a product, provided the materials are not first reclaimed
- used or reused as effective substitutes for commercial products provided they have not been reclaimed, or
- returned to the original process from which they were generated without first being reclaimed (material must be used as a substitute for raw material feedstock).

These materials are not considered solid waste.

Although the direct reuse provisions exempt certain materials from being solid wastes, there are limits to these exemptions. Materials that are used/reused as ingredients or substitutes for commercial products, but are also placed on the ground or incorporated into products placed on the ground (i.e., that are used in a manner constituting disposal) remain solid wastes. Also, if a material is used or reused by being burned for energy recovery or used to produce a fuel, it remains a solid waste. Finally, if a material

is speculatively accumulated or is “inherently waste like,” the material remains a solid waste regardless of the manner in which it is recycled.

The burden of proof that a particular material is not a solid waste and is, therefore, exempt from regulation lies with the person making the claim. This person must be able to demonstrate that there is a market for the material and that the specific use/reuse meets the condition of the exclusion. Closed-loop recycling processes also are excluded from regulation (40 CFR 261.4).

In addition, three case-by-case variances can be granted by the Regional EPA Administrator to exclude a material from classification as a “solid waste,” the following two of which involve recycling:

- A material is reclaimed and then reused as a feedstock within the original primary production process in which the material was generated if the reclamation operation is an essential part of the production process, or
- A material has been reclaimed but must be reclaimed further before recovery is complete if, after initial reclamation, the resulting material is commodity-like.

The U.S. EPA has also established a policy identifying criteria that may indicate sham recycling that is actually a surrogate for hazardous waste treatment or disposal. If a person uses a secondary material as is (in a production process), that person must be able to show that the secondary material is as effective as the raw material it is replacing. Also, if the material does not contribute any necessary or significant element to a product of the production process, the recycling may be a sham. Other indicators of sham recycling are use of a secondary material in excess of the amount necessary for a particular process and the handling of a secondary material without regard to economic loss. The burden of proof for the legitimacy of a claimed regulatory exemption rests solely on the recycler.

For secondary materials subject to regulation as a solid waste and potentially as a hazardous waste, specific standards exist for some types of hazardous waste reuse or reclamation activities. Generators and transporters of recyclable materials (hazardous wastes that will be recycled) generally are subject to 40 CFR Parts 262 (generator requirements) and 263 (transporter requirements) of Subtitle C, as well as notification requirements of Section 3010 of RCRA. Additionally, recycling facilities that store recyclable materials prior to recycling are subject to notification requirements and Subtitle C hazardous waste storage requirements. However, in general, the recycling process itself currently is exempt from regulation under Subtitle C. Recycling facilities that do not store recyclable materials before recycling are subject only to Subtitle C notification and manifest requirements.

Some particular recyclable materials are not subject to the full generator, transport, and storage requirements of Subtitle C, but are only subject to the limited provisions of Part 266 (again, the actual recycling process is not regulated; only the storage prior to recycling is subject to full Subtitle C regulation). Recyclable materials regulated under Part 266 include:

- hazardous waste burned for energy recovery
- precious metal reclamation
- spent lead-acid batteries
- recyclable materials used in a manner constituting disposal.

4.5.2 State and Local Regulations

State and local requirements can vary widely. Therefore, it is important to determine what the requirements are for a specific location. For spent ABM that is not RCRA hazardous, the following regulatory agencies potentially could have cognizance:

- state air board or air quality management district
- state water board
- state environmental protection agency (or department of environmental protection)
- county department of public health (or similar agency, if applicable)
- city department of public health (or similar agency, if applicable).

The names of these organizations may vary widely from region to region, and the above list is not necessarily complete. A list of addresses and phone numbers of state environmental regulatory agencies, and a list of U.S. EPA information hotlines and other sources of regulatory information pertaining to recycling are provided in Appendix B.

Some states have established requirements that are more stringent than those of the federal government for determining what waste is considered hazardous. Thus, spent ABM that is not hazardous under RCRA potentially could be considered hazardous by a particular state and must be handled and disposed of according to the state or local requirements. For example, California requires a slightly different testing procedures for determining toxic metals content and leachability. Also, the state has established lower concentrations for toxic metals and includes several additional metals such as copper that are not regulated under RCRA.

4.5.2.1 Summary of California EPA Policy Regarding “Use in a Manner Constituting Disposal.” California is one of a handful of states that have promulgated policy pertaining to recycling hazardous wastes into construction materials and specifying acceptance criteria for the types of wastes or byproducts that may be recycled. On August 18, 1995, the California EPA, Department of Toxic Substances Control (DTSC), Alternative Technology Division in Sacramento issued a management memo dated August 1995 for “The Use of Recyclable Materials in Asphalt Concrete and Concrete (Use Constituting Disposal or UCD)” (Appendix C). The purpose of this policy is to encourage the recycling of suitable wastes into construction materials and to establish conditions to assure that the recycling occurs safely and can be monitored as necessary to prevent abuses. Several of these conditions, which are described more fully in Appendix C, are as follows:

- The policy applies only to non-RCRA (California-only) hazardous wastes.
- For wastes failing the California WET test, the contaminant in the resulting construction material needs to be “chemically-bound.” The effect of contaminant dilution by other ingredients in the construction materials needs to be accounted for by increasing the measured leachable concentration by the dilution factor so that the component of immobilization due to chemical binding can be assessed. The WET soluble metal content of the asphalt-treated ABM must adhere to STLC standards after accounting for the effect of dilution.
- Recyclable materials should add no significant hazard to public health or the environment, either in the recycling process or in the final product.

- The recyclable materials must be used beneficially; that is, the material must meet accepted performance standards such as Caltrans (California Department of Transportation) specifications and must be made for commercial use.

Clearly, compliance with these criteria will involve some testing and evaluation. Demonstrating compliance with the metals leaching criteria will require laboratory or field treatability tests to evaluate the extent of metals immobilization due to asphaltic binder ingredients. Compliance with the criteria pertaining to hazards posed by the recycling process or product may require the performance of a quantitative risk assessment.

4.5.2.2 California Hazardous Waste Management Compliance Issues. The regulations summarized above specify when a hazardous byproduct is recyclable. Once that recyclability is demonstrated, for category 2 and 3 wastes, it will still be necessary to manage that recycling project in compliance with applicable state, local, and/or U.S. EPA waste management regulations.

As in the previous sections, it is not possible to define these regulations and policies for every region, as they will vary significantly from region to region. However, it is instructive to indicate the types of compliance issues that may exist, using California as an example.

In California, hazardous waste control requirements are set forth in the California Health and Safety Code, Division 20, Chapter 6.5, Section 25100 et seq. and regulations have been adopted to implement this section of the statutory code. Recyclable materials are subject to these requirements unless a variance is issued by the California DTSC or unless the material is excluded or exempted from classification as a waste under Section 25143.2(b), (c), or (d) or California's hazardous waste management regulations (adopted pursuant to Sections 25150 and 25151).

Materials exempted or excluded under Section 25143.2, subdivisions (b) or (d), must be managed in accordance with the requirements for management of a recyclable material specified in 25143.9. Under 25143.9(a), if a material is held in a container or tank, the container or tank must be labeled, marked, and placarded in accordance with DTSC hazardous waste labeling, marking, and placarding requirements applicable to generators, except that the container or tank would be labeled or marked clearly with the words "Excluded Recyclable Material" instead of the words "Hazardous Waste," and manifest document numbers would not be applicable.

Under 25143.9(b), the owner or operator of the business location where the material is located must have a business plan that meets the California requirements given in Section 25504, including but not limited to, emergency response plans and procedures, as described in subdivision (b) of Section 25504, which specifically address the material meet the DTSC's emergency response and contingency requirements that are applicable to generators of hazardous waste.

Section 25143.9(c) requires that the recyclable material be stored and handled in accordance with all local ordinances and codes governing the storage and handling of the hazardous material, including but not limited to, fire codes. If a local jurisdiction does not have an ordinance or code requiring secondary containment for hazardous material storage areas, then the material must be stored in tanks, waste piles, or containers meeting the DTSC's interim status regulations establishing design standards applicable to tanks, waste piles, or containers storing hazardous waste. Finally, under Section 25143.9(d), there are additional requirements if the material is being exported to a foreign country.

Although recyclable materials are not required to comply with the same regulations applied to hazardous waste generators, there is a statutory provision that affects the length of time that recyclable materials can be stored. Under Section 25413.2(e), materials that are accumulated speculatively do not

qualify for the exemptions under Section 25143.2. Because California has not specified a definition of speculative accumulation, the definition established by the U.S. EPA in 40 CFR 261.1(c)(8) applies. Under this definition, a recyclable material is not accumulated speculatively if the person accumulating it can show that the material is potentially recyclable and has a feasible means of being recycled; and that during the calendar year (commencing on January 1), the amount of material that is recycled or transferred to a different site for recycling equals at least 75% by weight or volume of the amount of that material accumulated at the beginning of the period.

Persons recycling more than 100 kilograms per month of recyclable material are required to provide reports to the local health officer or other local public officer authorized to implement the statute (see Section 25143.10). The following information is required to be provided in writing every 2 years:

- the name, site address, mailing address, and telephone number of the owner or operator of any facility that recycles the material
- the name and address of the generator of the recyclable material
- documentation that the requirements of any exemptions or exclusions pursuant to Section 25143.2 are met including, but not limited to, all of the following:
 - where a person who recycles the material is not the same person who generated the recyclable material, documentation that there is a known market for disposition of the recyclable material and any products manufactured from the recyclable material.
 - where the basis for the exclusion is that the recyclable material is used or reused to make a product or as a safe and effective substitute for a commercial product, a general description of the material and products, identification of the constituents or group of constituents, and their approximate concentrations, which would render the material or product hazardous under the regulation adopted pursuant to Sections 25140 and 25141, if it were a waste, and the means by which the material is beneficially used.

This information must be provided in the format developed by the California Conference of Directors of Environmental Health in consultation with the DTSC. Also, if the person recycling the material is not the same person who generated the recyclable material, then the person who recycles the material is required to provide the generator with a copy of the information listed above.

If the exclusion of the recyclable material is questioned and the regulatory authority brings action against owner or operator using the recyclable material, the burden of proof that the exclusion is valid lies with the owner or operator, not with the agency. The owner or operator would be required to provide information on the management of the material and to maintain adequate records to demonstrate that there is a market for disposition of the material (Section 25143.2, subdivision (f)).

4.5.2.3 Spent ABM Reuse in Washington and Oregon. The states of Washington and Oregon each have state regulations that potentially could favor recycling of state-only hazardous waste because of restrictions on landfilling such materials. A brief summary of these regulations is discussed below.

Washington's Dangerous Waste Guidelines (Washington Administrative Code [WAC] Chapter 173-303) have adopted TCLP testing parameters that are identical to the federal regulations specified under RCRA. However, Washington Department of Ecology Technical Information Memorandum (TIM)

86-1 specifies additional analytical testing requirements for foundry slag and baghouse wastes from the sandblasting industry. TIM 86-1 specifies three additional metals: copper, nickel, and zinc. This memorandum stipulates that if the cumulative concentrations of these three metals in their soluble form exceeds 5 parts per million (ppm), then additional criteria under aquatic toxicity testing must be reviewed prior to disposal through a municipal facility. These criteria may not apply if the materials are recycled or used in additional industrial processes. It is not clear how this would apply to spent ABM; however, recycling potentially could be more favorable if the presence of these metals caused disposal costs to be greater.

The Oregon Hazardous Waste Guidelines (Oregon Administrative Rules (OAR) Chapter 340) also have adopted the federal TCLP criteria for heavy metals. However, the Oregon Department of Environmental Quality has recently promulgated legislation for the management of ABM from ship repair activities. This segment of legislation specifically targets the ship repair industry and the use of antifouling paints. Under this regulation, spent antifouling residues may be considered pesticides. Because antifouling paints are potential pesticides, and sandblast grit waste containing such is subject to Oregon's Aquatic Toxicity Test (OAR 340-101-033). If the sandblast grit fails the original TCLP parameters, the material is then classified as a federally regulated hazardous waste and an aquatic toxicity test is not necessary; it must be managed as a hazardous waste. If the waste passes the TCLP test and fails the aquatic toxicity test, it is classified as an Oregon State-Only dangerous waste and must be managed as a hazardous waste. Upon further review of this legislation, this rule is applicable to materials primarily managed and disposed through municipal landfill facilities and does not include those wastes managed through a legitimate recycling or reuse program. The Department of Environmental Quality does allow disposal of spent grit that fails the aquatic toxicity test if the solid waste landfill meets design criteria specified in 40 CFR 258.40.

5.0 SUMMARY AND CONCLUSIONS

Section 2 describes physical and chemical aspects of new and spent ABM, Section 3 discusses some specific approaches to recycling spent ABM, and Section 4 describes factors to consider when reviewing and selecting recycling options. These sections outline some guideposts to possible markets for your spent ABM or similar wastes and indicate factors to consider when searching for recycling options. The analysis is a complex task which must be done for a specific waste material.

Due to the lack of a clear definition of what constitutes valid recycling, the user needs to be particularly careful when identifying options for hazardous material recycling. The ultimate interpretation rests with the federal and local regulators.

Once the potential markets are identified, some basis must be found for establishing specifications for materials. Reliable materials commerce requires some acceptable standards describing the composition, quality, and properties of recycled materials. The specifications may be based on the material origin, composition, end use performance, or other characteristics. Potential end users may avoid recycled material if they are uncertain about the impurity levels or how well the quality of the material will be controlled.

In general, developing a specification will require negotiation between the supplier and user. Some guidance is available in the form of ASTM or other specifications that include or can be applied to recycled materials. The U.S. EPA, under the provisions of RCRA, is encouraging government agencies to allow use of recycled materials. However, most existing specifications are written to ignore or possibly even preclude recycled materials. Creative use of existing specification may be needed to reach a definition of material composition and properties that is acceptable to the buyer and seller.

Material characterization for recycling requires a somewhat different outlook and approach than is typical for waste treatment studies. Waste characterization for waste treatment and disposal usually focuses mainly on the amounts of contaminant present. The mineral form of the contaminant and the composition and form of the matrix are considered only in light of how they may affect the performance of treatment or disposal options. Recycling requires thinking of the entire body of waste material as a product. As a result, its total composition, chemical speciation, and physical form need to be established early in the characterization process.

Waste materials, particularly those from CERCLA sites, usually have highly variable compositions. End users prefer a reliable stream of materials with predictable composition. The waste supplier may, therefore, need to provide pretreatment to homogenize and sample the material to prepare a product that is acceptable for the user.

In the face of competition for traditional raw materials sources, the waste generator or supplier often needs to take an active role to seek out uses for the waste material. Recycling can succeed only if there are markets for the waste material. In general, users of recycled materials are in a buyer's market. A large new source of waste materials available for recycling can saturate end use markets. These elements can help in finding a home for waste materials:

- established and effective specifications
- creative efforts to identify possible uses

- providing a reliable supply of consistent material
- programs to improve public awareness of recycling potential.

These seem daunting tasks that lie beyond the scope of normal waste processing and disposal. However, significant benefits can be achieved in reduced liability and possibly reduced cost if the waste material is recycled rather than sent for disposal.

The individual waste generator can contribute, but efforts are needed from a variety of groups to help expand recycling of industrial wastes. The task is not impossible. Europe has installed an infrastructure for recycling a variety of industrial wastes. Technologies and systems are growing in the United States to support recycling.

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APPENDIX A

ABRASIVE BLASTING MEDIA QUALIFIED FOR USE ON U.S. NAVY SHIPS

QUALIFICATIONS CERTIFIED
MAY 1990

QPL-22262-18
20 June 1995
SUPERSEDING
QPL-22262-17
21 May 1993

QUALIFIED PRODUCTS LIST

OF

FSC 5350

PRODUCTS QUALIFIED UNDER MILITARY SPECIFICATION

MIL-A-22262

ABRASIVE BLASTING MEDIA SHIP HULL BLAST CLEANING

This list has been prepared for use by or for the Government in the acquisition of products covered by the subject specification and such listing of a product is not intended to and does not connote indorsement of the product by the Department of Defense. All products listed herein have been qualified under the requirements for the product as specified in the latest effective issue of the applicable specification. This list is subject to change without notice; revision or amendment of this list will be issued as necessary. The listing of a product does not release the contractor from compliance with the specification requirements.

THE ACTIVITY RESPONSIBLE FOR THIS QUALIFIED PRODUCTS LIST IS THE NAVAL SEA SYSTEMS COMMAND, SEA 03R42, 2531 JEFFERSON DAVIS HWY, ARLINGTON, VA 22242-5160.

GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	BARTON 1640 GARNET	NAVSHIPYD, MARE 9631, Ser 134.6/ 62 and NEHC Rpt. 6266, Ser 34Bdbm 06015	Barton Mines Corp. P.O. Box 400 North Creek, NY 12853 Plant: Hudson River Plant Route 28 North Creek, NY 12853
	STARBLAST XL	NAVSHIPYD, MARE 9631, Ser 134.6/ 79 and NEHC Rpt. 6260, Ser 34Bnhp/ 2014	E.I. du Pont de Nemours & Co., Inc. Chestnut Run Plaza Building 709 Wilmington, DE 19880- 0709 Plant: Florida Plant Route 230 Starke, FL 32091

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	Emerald Creek Garnet	NAVSHIPYD, MARE 9631, Ser 134.6/ 158 and NEHC Rpt. 6270, Ser 342/0548	Emerald Creek Garnet P.O. Box 190 Fernwood, ID 83830 Plant: Route 4 Emerald Creek Road Fernwood, ID 83830
	Black Diamond	NAVSHIPYD, MARE 9631, Ser 134.6/ 151 and NEHC Rpt. 4121, Ser 34Bvs/ 02176	Foster Dixiana Corp. P.O. Box 2005 Columbia, SC 29202 Plant: 5360 Bainbridge Blvd. Chesapeake, VA 23320
	Black Diamond (CX-8)	NAVSHIPYD, MARE 9631, Ser 134.6/ 56 and NEHC Rpt 4123, Ser 34Dndb/ 01007	Foster Dixiana Corp. P.O. Box 2005 Columbia, SC 29202 Plant: Hardeeville Ind. Park - Hwy. 321 Hardeeville, SC 29927
	ROM 30x60 Garnet Abrasive GMA 30X60 GMA 60 mesh GMA 80 mesh	NAVSHIPYD, MARE 9631, Ser 134.6/ 178 and NEHC Rpt. 6270, Ser 34Bns 06336	Garnet Millers Assoc. Pty. Ltd. (GMA), c/o Barton Mines Corp., Suite 190 1658 Cole Blvd. Golden, CO 80401 Plant: Gould Road Geraldton, WA 6530 Australia
	CAMEL BLACK	NAVSHIPYD, MARE 9631, Ser 134.6/95 and NECH Rpt. 6270 Ser 34B/4697	Genstar Stone Products Company Executive Plaza IV Hunt Valley, MD 21031-1091 Plant: 10300 Pulaski Highway White Marsh, MD 21162

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	GREEN DIAMOND	NAVSHIPYD, MARE 9631, Ser 134.6/ 61 and NEHC Rpt. 6270, Ser 34Baj/ 06016	Glenbrook Nickel Co. 5094 Glenbrook Loop Rd P.O. Box 85 Riddle, OR 97469 Plant: 6th & E Street Riddle, OR 97469
	Kleen Blast	NAVSHIPYD, MARE ISLAND Rpt. 9631 Ser 134.6/34 & NEHC Rpt. 6270 Ser 42p/08213	Kleen Blast Abrasives 2400 Old Crow Canyon Road, #AZ San Ramon, CA 94583 Plant: Pacific Abrasive and Supply West Carson Rd. Grand Forks, B.C. Canada V0H 1-H0
	Sharpshot M-60 Sharpshot F-80	NAVSHIPYD, MARE ISLAND Rpt. 9631 Ser 134.6/67 & NEHC Rpt. 6266 Ser 422mb/12025	Minerals Research & Recovery of Arizona, Inc. 4565 South Palo Verde Suite #203 Tucson, AZ 85714 Plant: Highway 85 Ajo, AZ 85321
	Ferro-Blast/ Best Grit 73	NAVSHIPYD, MARE Rpts. 9631, Ser 134.6/25 & 9631, Ser 134.6/169 and NEHC Rpt. 4121, Ser 34Bm/12187	RDM Multi-Enterprises, Inc. P.O. Box 179 Anaconda, MT 59711 Plant: 1/2 Mile East of Anaconda on Montana Highway #1 Anaconda, MT 59711

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	Black Beauty 1240 2040	NAVSHIPYD, MARE 9631, Ser 134.6/ 181 and NEHC Rpt. 6720, Ser 422hc/ 03299	Reed Minerals Div. Harsco Corporation 8149 Kennedy Avenue Highland, IN 46322 Plant: State Road 176 Drakesboro, KY 42337
	Black Beauty 1040 1243 2043	NAVSHIPYD, MARE Rpts. 9631, Ser 134.6/202 & Ser 134.6/ 224 & NEHC Rpt. 6720, Ser 34Bvs/11513	Reed Minerals Div. Harsco Corporation 8149 Kennedy Avenue Highland, IN 46322 Plant: River Rd. at Merrimack Power Station Concord (Bow), NH 03302
	Stan-Blast	NAVSHIPYD, MARE 9631, Ser 134.6/ 48 and NEHC Rpt. 6270, Ser 422c/ 08253	Stan-Blast Abrasives Company, Inc. 2525 South Shore Blvd. Suite 301 League City, TX 77573 Plant: 5712 Port Industrial Galveston, TX 77552
	Stan-Blast	NAVSHIPYD, MARE 9631, Ser 134.6/ 132 and NEHC Rpt. 6270, Ser 422c/ 08253	Stan-Blast Abrasives Company, Inc. 2525 South Shore Blvd. Suite 301 League City, TX 77573 Plant: 3300 River Road Harvey, LA 70059
	Black Blast	NAVSHIPYD, MARE 9631, Ser 134.6/ 11 and NEHC Rpt. 4121, Ser 34Bns/ 11017	Virginia Materials P.O. Box 7400 Norfolk, VA 23509 Plant: 3306 Peterson Street Norfolk, VA 23509

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APPENDIX B

LISTING OF REGULATORY INFORMATION SOURCES

HAZARDOUS WASTE CONTACTS

ALABAMA

Alabama Dept of Environmental Management
Land Division
1751 Federal Drive
Montgomery, AL 36130
334-271-7730

ALASKA

Dept. of Environmental Conservation
410 Willoughby Avenue, Suite 105
Juneau, AK 99801-1795
Program Manager: 907-465-5150
Northern Regional Office (Fairbanks): 907-451-2360
South-Central Regional Office (Juneau): 907-563-6529
Southeast Regional Office (Juneau): 907-465-5350

ARIZONA

Arizona Dept. of Environmental Quality
Waste Programs Bureau
3033 North Central Avenue
Phoenix, AZ 85012
602-207-2300

ARKANSAS

Dept. of Pollution Control and Ecology
Hazardous Waste Division
P.O. Box 8913
8001 National Drive
Little Rock, AR 72219-8913
501-562-7444

CALIFORNIA

California EPA
Dept. of Toxic Substances Control
400 P Street, 4th Floor
P.O. Box 806
Sacramento, CA 95812-0806
916-322-0504

California EPA
State Water Resources Control Board
Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100
916-657-2390

COLORADO

Public and Environment Dept.
Hazardous Materials and Waste Management Division
4300 Cherry Creek Drive South
Denver, CO 80222
303-692-3300

CONNECTICUT

Dept. of Environmental Protection
Waste Management Bureau
Waste Engineering and Enforcement Division

79 Elm Street
Hartford, CT 06106
203-424-3023

Connecticut Resource
Recovery Authority
179 Allyn Street, Suite 603
Professional Building
Hartford, CT 06103
203-549-6390

DELAWARE

Dept. of Natural Resources and Environmental Control
Division of Air and Waste Management
Hazardous Waste Office
89 King's Highway
P.O. Box 1041
Dover, DE 19903
302-739-3689

DISTRICT OF COLUMBIA

Dept. of Consumer and Regulatory Affairs
Environmental Regulation Administration
Pesticides and Hazardous Waste Management Branch
2100 Martin Luther King Avenue, SE, Suite 203
Washington, DC 20020
202-645-6617

FLORIDA

Environmental Protection Dept.
Waste Management Division
Solid and Hazardous Waste Bureau
3900 Commonwealth Boulevard
Tallahassee, FL 32399
904-488-0300

GEORGIA

Georgia Dept. of Natural Resources
Environmental Protection Division
Hazardous Waste Management Branch
Floyd Towers East, Suite 1154
205 Butler Street, SE
Atlanta, GA 30334
404-656-7802

HAWAII

Dept. of Health
Solid and Hazardous Waste Branch
5 Waterfront Plaza, Suite 250
919 Ala Moana Boulevard
Honolulu, HI 96813
808-586-4225

IDAHO

Dept of Health and Welfare
Division of Environmental Quality
280 North 8th Street
Boise, ID 83720
208-334-5840

ILLINOIS

Energy and Natural Resources Dept.
Solid Waste and Renewable Resources Division
325 West Adams Street, Room 300
Springfield, IL 62704
217-785-2800

INDIANA

Dept. of Environmental Management
Office of Solid and Hazardous Waste
100 North Senate Avenue
Indianapolis, IN 46206
317-232-3210

IOWA

Dept. of Natural Resources
Waste Management Assistance Division
Wallace State Office Building
900 East Grand
Des Moines, IA 50319
515-281-8975

KANSAS

Dept. of Health and Environment
Bureau of Waste Management
Forbes Field, Building 740
Topeka, KS 66620
913-296-1612

KENTUCKY

Natural Resources and Environmental Protection
Cabinet
Division of Waste Management
18 Reilly Road
Frankfort, KY 40601
502-564-4245

LOUISIANA

Dept. of Environmental Quality
Solid and Hazardous Waste Division
11720 Airline Highway
Baton Rouge, LA 70817
504-765-0249

MAINE

Dept. of Environmental Protection
Bureau of Hazardous Materials and Solid Waste Control
State House Station #17
Augusta, ME 04333
207-289-2651

MARYLAND

Environment Dept.
Waste Management Administration
2500 Broening Highway
Baltimore, MD 21201
410-631-3304

MASSACHUSETTS

Dept. of Environmental Protection
Hazardous Waste Division
One Winter Street, 5th Floor
Boston, MA 02108

617-292-5853

MICHIGAN

Michigan Dept. of Natural Resources
Waste Management Division
P.O. Box 30241
Lansing, MI 48909
517-373-2730

MINNESOTA

Pollution Control Agency
Hazardous Waste Division
520 Lafayette Road North
St. Paul, MN 55155
612-297-8502

MISSISSIPPI

Dept. of Environmental Quality
Division of Solid and Hazardous Waste Management
P.O. Box 10385
Jackson, MS 39289
601-961-5047

MISSOURI

Dept. of Natural Resources
Waste Management Program
P.O. Box 176
Jefferson City, MO 65102
314-751-3176
Missouri Natural Resources Hotline: 800-334-6946

MONTANA

Dept. of Health and Environmental Sciences
Waste Management Division
Cogswell Building, Room B 201
Helena, MT 59620
406-444-1430

NEBRASKA

Environmental Quality Dept.
P.O. Box 98922
Lincoln, NE 68509
402-471-2186

NEVADA

Conservation and Natural Resources Dept.
Division of Environmental Protection
Waste Management Program
123 West Nye
Carson City, NV 89710
702-687-4670

NEW HAMPSHIRE

Dept. of Environmental Services
Waste Management Division
Health and Welfare Building
6 Hazen Drive
Concord, NH 03301
603-271-3406

NEW JERSEY

Dept. of Environmental Protection and Energy
Solid Waste Management
401 East State Street, CN-423
Trenton, NJ 08625
609-530-8591

NEW MEXICO

Environmental Improvement Division
Hazardous Waste Bureau
P.O. Box 26110
Santa Fe, NM 87502
505-827-2775

NEW YORK

Dept. of Environmental Conservation
Division of Hazardous Substances Regulation
50 Wolf Road, Room 229
Albany, NY 12233
518-457-6934
SQG Hotline: 800-462-6553

NORTH CAROLINA

Dept. of Environmental, Health, and Natural Resources
Hazardous Waste Section
P.O. Box 27687
Raleigh, NC 27611
919-715-4140

NORTH DAKOTA

Dept. of Health
Consolidated Laboratories
Division of Waste Management
P.O. Box 5520
1200 Missouri Avenue, Room 302
Bismark, ND 58502
701-328-5166

OHIO

Ohio EPA
Division of Hazardous Waste
P.O. Box 1049

Columbus, OH 43216
614-644-2917

OKLAHOMA

Environmental Quality Dept.
Waste Management Division
1000 NE Tenth Street
Oklahoma City, OK 73117
405-271-7041

OREGON

Dept. of Environmental Quality
Hazardous Waste Division
811 SW Sixth Avenue
Portland, OR 97204
503-229-6585

PENNSYLVANIA

Dept. of Environmental Resources
Bureau of Waste Management
Director's Office
P.O. Box 2063
Harrisburg, PA 17105
717-787-9870

RHODE ISLAND

Dept. of Environmental Management
Division of Air and Hazardous Materials
291 Promenade Street
Providence, RI 02908
401-277-4700

SOUTH CAROLINA

Dept. of Health and Environmental Control
Bureau of Solid and Hazardous Waste Management
2600 Bull Street
Columbia, SC 29201
803-734-5202

SOUTH DAKOTA

Dept. of Environment and Natural Resources
Office of Waste Management
500 East Capital Avenue
Pierre, SD 57501
605-773-3351

TENNESSEE

Environment and Conservation Dept.
Solid Waste Management Division
401 Church Street, 21st Floor
Nashville, TN 37248
615-532-0780

TEXAS

Natural Resource Conservation Commission
Industrial and Hazardous Waste Division
P.O. Box 13087
Capital Station
Austin, TX 78711
512-239-2324

UTAH

Dept. of Environmental Quality
Division of Solid and Hazardous Waste
P.O. Box 144810
Salt Lake City, UT 84114
801-538-6170

VERMONT

Natural Resources Agency
Environmental Conservation Dept.
Hazardous Material Division
103 South Main Street
Waterbury, VT 05676
802-241-3888

VIRGINIA

Natural Resources Office
Environment Quality Dept.
629 East Main Street
Richmond, VA 23219
804-762-4020
Hazardous Waste Hotline: 800-552-2075

WASHINGTON

Dept. of Ecology
Solid and Hazardous Waste Program
P.O. Box 47600, Row 6, Building 4
Olympia, WA 98504
360-407-6103

WEST VIRGINIA

Environmental Protection Bureau
Waste Management Division
1356 Hansford Street
Charleston, WV 25301
304-558-5929

WISCONSIN

Dept. of Natural Resources
Solid and Hazardous Waste Management
P.O. Box 7921
Madison, WI 53707
608-266-1327

WYOMING

Dept. of Environmental Quality
Solid Waste Management Division
Herschler Building
122 West 25th Street
Cheyenne, WY 82002
307-777-7752

ADDITIONAL SOURCES OF INFORMATION

1. Phone & Hotline Information

- RCRA/Superfund Hotline
1-800-424-9346 (in Washington, DC 260-3000)
- EPA Small Business Ombudsman Hotline
1-800-368-5888 (in Washington, DC 557-1938)
- National Response Center
1-800-494-8802 (in Washington, DC 260-2675)
- Transportation of Hazardous Materials
202-366-4488
- Toxic Substance Control Act (TSCA) Assistance
Service
202-554-1404
- Center for Hazardous Materials Research (CHMR)
Hotline
1-800-334-2467

2. EPA Documents

- EPA/530-SW-86-019, September 1986, *Understanding the Small Quantity Generator, Hazardous Waste Generator.*
- EPA/530-SW-037, November 1986, *Solving the Hazardous Waste Problem — EPA's RCRA Program.*

3. *Journal of Protective Coatings & Linings* (available from Technology Publishing Co., 2300 Wharton St., Suite 310, Pittsburgh, PA 15203 [800-837-8303])

4. Other Publications

- *Bridge Paint Removal, Containment & Disposal*, Synthesis Report 20-05/20-09, 1992. Transportation Research Board, 2101 Constitution Ave., Washington, DC 20418
- *Removal of Lead-Based Bridge Paints*, NCHRP Report 265, December 1983, Transportation Research Board.
- *Industrial Lead Paint Removal Handbook*, SSPC 91-18, November 1991. Available from SSPC, 4400 Fifth Ave., Pittsburgh, PA 15213.

APPENDIX C

THE USE OF RECYCLABLE MATERIALS IN ASPHALT CONCRETE AND CONCRETE USE CONSTITUTING DISPOSAL OR UCD

**HAZARDOUS WASTE MANAGEMENT PROGRAM
MANAGEMENT MEMO**

MANAGEMENT MEMO #: EO-95-010-MM

TITLE: USE CONSTITUTING DISPOSAL

AFFECTED PROGRAMS: Hazardous Waste Management Program
Site Mitigation Program

ISSUE:

The Department of Toxic Substances Control (DTSC) is now developing regulations to address the "use constituting disposal" restriction as it pertains to recyclable materials that are non-RCRA hazardous wastes in section 25143.2(e)(2) of the Health and Safety Code (HSC). A "non-RCRA" waste is hazardous waste that is regulated in California but is not a Resource Conservation and Recovery Act (RCRA) waste. A RCRA hazardous waste is any waste identified as a hazardous waste in Part 261, Subchapter I, Chapter 1 of Title 40 of the Code of Federal Regulations (40 CFR). The "use constituting disposal" restriction affects the eligibility of recyclable materials for the exclusions and exemptions provided under HSC section 25143.2. The purpose of this management memo is to provide interim guidance on how to interpret "use constituting disposal," and therefore determine if a waste is subject to regulation pursuant to HSC section 25143.2(e)(2), until the regulations are adopted.

BACKGROUND:

HSC section 25143.2 addresses exclusions and exemptions for recyclable materials that are managed in a specified manner. Note that a recyclable material is defined as a hazardous waste that is capable of being recycled.¹ HSC section 25143.2 also lists conditions under which the recyclable materials must be fully regulated as hazardous wastes, regardless of the exclusions from classification as a waste and the exemptions from facility permitting requirements granted in this section. One such condition is when the materials are "used in a manner constituting disposal." This restriction is addressed separately for RCRA wastes and non-RCRA wastes.

Under California law, there is no definition for "use constituting disposal." The U.S. Environmental Protection Agency (U.S. EPA) has defined "use constituting disposal" to mean placing recyclable materials or products derived from recyclable

¹ Ref. HSC section 25120.5.

materials on the land.² Under federal regulations, recyclable materials that are used in a manner constituting disposal are subject to regulation as solid wastes. At the same time, the U.S. EPA does not currently regulate products containing recyclable materials that are placed on the land if the recyclable materials have undergone a chemical reaction in producing the product so as to be physically inseparable from the product and the product meets the applicable treatment standards (or applicable prohibition levels where no treatment standards have been established) in subpart D, part 268, 40 CFR.

Since 1987, the DTSC has applied a set of criteria to recyclable materials placed on the land in determining whether or not such materials are "used in a manner constituting disposal." If these criteria are met, the recyclable materials are not regulated pursuant to HSC section 25143.2(e)(2) and may be eligible for the exclusions and exemptions under HSC section 25143.2 (b), (c) or (d). **The DTSC's criteria apply only to non-RCRA wastes.** The DTSC is currently writing regulations to address the issue of recyclable materials that are placed on the land ("use constituting disposal"). This management memo clarifies the criteria applied by the DTSC pending adoption of these regulations.

ACTION:

The following, which applies only to non-RCRA wastes, is the DTSC's present interpretation of the "use constituting disposal" restriction, i.e., of which recyclable materials are subject to regulation, in HSC section 25143.2(e)(2). This interpretation applies only until regulations addressing recyclable materials used in a manner constituting disposal or placed on the land are adopted.

A recyclable material that is placed on the land or used to produce a product which is placed on the land is regulated pursuant to HSC section 25143.2(e)(2) unless all applicable criteria listed below are met.

1. This criterion applies to situations where the recyclable material is used as an ingredient in the manufacture of a product. Hazardous constituents in the recyclable material whose concentrations are greater than or equal to the

² Ref. 50 Federal Register 618, January 4, 1985, and 40 CFR 266.20.

regulatory Soluble Threshold Limit Concentrations (STLCs)³ shall have chemically reacted or become physically bound so as not to leach from the product containing the recyclable material. Specifically, the hazardous constituents shall not leach out in concentrations that would exceed the applicable STLC, once the effect of dilution by other ingredients (as explained below) has been taken into account.

In order to meet this requirement, the following procedures must be used to evaluate the recyclable material and the product:

(a) Sampling and analysis:

- (1) Sampling shall be conducted according to the sampling methods described in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd edition, 1986, or one of the sampling methods listed in Appendix I, Chapter 11, Division 4.5, Title 22, California Code of Regulations (22 CCR); and
- (2) Analysis shall be conducted according to the Waste Extraction Test (WET), Appendix II, Chapter 11, Division 4.5, 22 CCR, or an alternative test method approved pursuant to 22 CCR section 66260.21

- (b) In order to demonstrate that the hazardous constituents in the recyclable material are bound in the product so that they would not exceed the applicable STLC, even when eliminating the effect of dilution by other ingredients, the following calculations must be used.

The concentration of the hazardous constituents in the final product, as determined by the WET, must be multiplied by the dilution factor inherent in combining the recyclable material with other materials. The dilution factor is calculated by dividing the weight of the final product made with the recyclable material by the weight of the recyclable material used in the product, or

³ As set forth in sections 66261.24(a)(2)(A) and (a)(2)(B), Division 4.5, Title 22 of the California Code of Regulations (22 CCR).

$$\frac{\text{weight of final product}}{\text{weight of recyclable material}} = \text{dilution factor}$$

If the ingredients in the product that are not recyclable materials contain the same hazardous constituents present in the recyclable material, the hazardous constituents in the ingredients that are not recyclable materials may be subtracted from the concentration of hazardous constituents in the final product, adjusted for dilution.

The final calculation of the hazardous constituents present in the product, as determined by taking into account the effects of dilution and, where applicable, the effects of hazardous constituents in ingredients that are not recyclable materials, must be less than the applicable STLC.

The following is an example of how these calculations can be done.

A ton of spent sandblast grit, which is hazardous due to a mean soluble lead concentration of 12 mg/L, is combined with nineteen tons of other aggregate and asphalt to produce twenty tons of asphaltic concrete. The dilution factor is thus 20 (twenty tons of final product, including the recyclable material, divided by the original one ton of recyclable material). The asphaltic concrete is then subjected to the WET and yields mean results for lead of 0.05 mg/l. This number is then multiplied by the dilution factor, 20, for a result of 1.00 mg/l. The aggregate that is not a recyclable material was tested with the WET and found to have a concentration of 0.05 mg/l lead. This concentration can be subtracted from 1 mg/l to give you 0.95 mg/l. This final calculation does not exceed the STLC for lead of 5 mg/l and therefore meets the criterion.

2. A recyclable material used as a substitute for a commercial product or a product containing a recyclable material shall not contain constituents that cause the product to exhibit hazardous characteristics pursuant to Chapter 11, Division 4.5, CCR 22, other than those constituents that are also found in the same or greater concentrations in a comparable commercial product. The only exception to this requirement is if the person claiming an exclusion obtains

the DTSC's written concurrence prior to using the recyclable material that:

- (a) the concentrations of hazardous constituents greater than those present in a comparable commercial product improve the quality of the product made from the recyclable material and do not increase the hazards to public health or the environment of that product; or
 - (b) if no comparable commercial product exists, the hazardous constituents in the recyclable material that cause the product to exhibit a characteristic of a hazardous waste are beneficial to the product and do not cause the product to pose a threat to public health or the environment.
3. The recyclable material must be used beneficially, as demonstrated by both of the following conditions:
- (a) Prior to use, the recyclable material and the product containing that material must each be certified by a qualified independent engineer registered in the state of California⁴ to meet the applicable standards or specifications for the intended use of the recyclable material or product of the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), the American National Standards Institute (ANSI), the Uniform Building Code (UBC), or the standards of a government agency having jurisdiction over the construction applications of that recyclable material or product. A nationally recognized industry standard, other than those mentioned, may be used with the prior written approval of the DTSC.
 - (b) There shall be no indications of sham recycling, including, but not limited to, use of the recyclable material or a product containing a recyclable material in excess of what is necessary to accomplish its function, handling of the recyclable material in a manner inconsistent with the economic value of the

⁴ By "qualified independent engineer", we mean an engineer whose registration (e.g., civil, mechanical, structural, etc.) is appropriate for the product she/he is certifying and who is not an employee of the person claiming an exclusion or exemption pursuant to HSC 25143.2.

material, or insufficient use of the recyclable material to accomplish its function.

Non-RCRA hazardous wastes managed according to the applicable criteria above will not be regulated pursuant to HSC 25143.2(e) and may therefore qualify for the exclusions and exemptions in HSC section 25143.2 if the requirements of a specific exclusion or exemption are met and none of the other provisions of subdivision (e) apply.

Examples of recyclable materials used in products placed on the land are spent sandblast grit, contaminated soils, foundry sands, ash, and demolition wastes, which may be used, among other things, as asphalt treated road base, landfill cover material, or aggregate in Portland cement concrete or an asphaltic concrete.

Use of recyclable materials as fertilizer, soil amendment, agricultural mineral, or an auxiliary soil and plant substance, with or without combination with other materials, is not covered by this management memo and is regulated separately.⁵ Used oil is also not covered by this management memo.⁶

This management memo will stay in effect until the promulgation of regulations regarding management requirements for recyclable materials that are placed on the land, i.e., used in a manner constituting disposal, or until it is replaced by a subsequent management memo or DTSC policy.

DISTRIBUTION:

Cal/EPA Access Bulletin Board System
Hazardous Waste Management Program Policy Mailing List

ATTACHMENTS: None

⁵ Ref. Article 8, Chapter 16, 22 CCR.

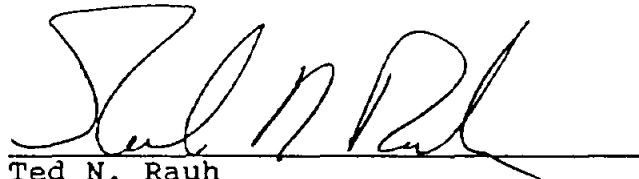
⁶ Ref. Article 13, Chapter 6.5, Division 20 of the Health and Safety Code.

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Use Constituting Disposal
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8/18/95
Date


Ted N. Rauh
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